Master Thesis

Mood controlled affective ambiences for the elderly

By

Pim Willems

Supervisors

Khiet Truong

Randy Klaassen

Dirk Heylen

14-08-2017

Abstract

The goal of this research is to develop an ambient lighting system that is controlled by the mood of a user. The ambient lighting system uses the physiological data of the user to intervene when necessary. The mood of the user is improved by changing the ambient lighting in the person's own living room. Prior to the development of the system, literature related to the system was analysed. This was followed by the development of the system and which was tested in two different experimental settings. First, an experiment was conducted focusing on validating the existing research, identifying the interaction of participants with the developed system and identifying the responses of the users to the changes in lighting. In total, 20 participants voluntarily participated in the experiment. Second, an experiment was conducted focussing on testing the effects of the ambient lighting on one participant over a longer period. The physiological data of this participant is measuring for a week, during which she reported the events that influenced her mood in a diary. The physiological data of the participant is mapped and a peak adaption algorithm within the system is used to analyse the data. The results show that the physiological and self-report data indicates an improvement in the mood of the participant. However, several semi-structured interviews were conducted with the participant to get in-depth information about thoughts and feelings. The interviews revealed that the participant experienced an effect of the ambient lighting on her mood. By changing the ambient lighting, the participant experienced the living room as cosier and more positive. According to the participant, a change in lighting changed her mood in positive way. The results of the experiments show that it is possible to improve the (experienced) mood by changing the ambient lighting. The developed system is tailored to one person, meaning that for further research a new system needs to be developed to support multiple users in the future.

Acknowledgements

First, I would like to thank my two daily supervisors, Khiet Truong and Randy Klaassen for their support of this research, for their input and knowledge about the subject. I am also grateful to my third supervisor Dirk Heylen for taking the time to grade my work. Finally, I want to thank my fellow students from the HMI master and CreaTe bachelor, who helped me with my experiments and gave their (unasked) advice when needed.

Pim Willems,

Enschede, August 2017

Table of Contents

List of Figures

List of Tables

1. Introduction

With the ageing of the population the percentage of elderly in the world grows each year. For example, in the Dutch elections of March 2017 over a quarter of the people that are allowed to vote are the age of 65 and over (NOS, 2017). One of the biggest problems with this group is the feeling of loneliness (Botek, 2014). A lot of elderly still live independent or live in an assisted living residence, which most of the time results in returning home to an empty living room in which they need to entertain themselves. By combining several small improvements to the home of the elderly it is possible to improve the negative mood (for example loneliness) of the elderly and make their living room a positive experience again. One of the simpler ways to do this, is to change the ambient lighting inside the living room to an interactive version which can measure the mood of the resident and change the lighting accordingly. This autonomous system should be able to do at least two things, namely measuring the mood of the person living in this room and controlling the Lighting around the house. This research area is a combination between two areas, namely Mood recognition and adaptive Lighting, which are combined into Emphatic Lighting. Emphatic Lighting is the kind of lighting that can automatically adapt to how the users feels or behaves when they are present in the room it is installed in. The emphatic lighting discussed in this thesis focusses on a system that can measure the negative affective states or moods, such as loneliness or gloominess, and improve these states. The improvement of these states is done by building on existing research on the effect of lighting and the colours of lighting to improve the negative states.

1.1. Research goal

As a basis for this Master Thesis a preliminary research (or research topics) was conducted (Willems, 2017). The goal of this preliminary research is to explore the research area of emphatic lighting, to look at the existing technologies and research and it concluded the exploration with a research question. The focus of the preliminary research and this master thesis is on the whole area of emphatic lighting, consisting out of self-reported mood measuring, behavioural mood measuring, existing products, the effect of lighting on mood, ambient lighting and the target group. The preliminary research concluded with one main research question and four sub-questions to support the main one, which focus on a gap in this area of research which is not discussed in existing research yet. This results in the following main research question, which will be answered in this thesis:

- How can a system be developed to automatically measure and increase the mood of the elderly by changing the lighting in their living room?

And the sub research questions are:

1. Which mood measuring method can be best used to measure the effect of light on the mood of the elderly?
2. How can the measured signals be mapped to mood models?
3. What is the user experience and how do the elderly respond to the ambient lighting in the room?
4. In what way does the lighting in the living room need to change to improve the mood of the elderly?

1.2. Structure and methodology

The goal of this thesis is to develop a system that can automatically measure and increase the mood by changing the ambient lighting. To achieve this goal, two versions or iterations of this system are developed. The first experiment focusses on the results from the literature studies and will replicate these findings in a new setting. The second experiment focusses on testing the system that can achieve the goal of this thesis. These experiments are designed in such a way that they can help answer the research questions. This research will start with the definition of mood and affective states, which will be used throughout this document. With this definition, we will look into mood measuring methods, the effect of lighting and the target group. Next, we will continue by deciding about which mood measuring methods are best used to measure mood, based upon the preliminary research. These mood-measuring methods then need to be mapped in such a way that an autonomous system can do the measuring and give the system the required information to adapt the lighting. The next part of the system is the ambient lighting that is used to improve the negative mood of the elderly. By combining the ambient lighting with mood, it is possible to define the design of two experiments that are used to answer the research questions. The results per experiment are then discussed in combination with how the results effect the next steps in the development of the system. After the experiment a general conclusion is made and the research questions are answered. A visual overview of the structure of this thesis can be found in Figure 1.

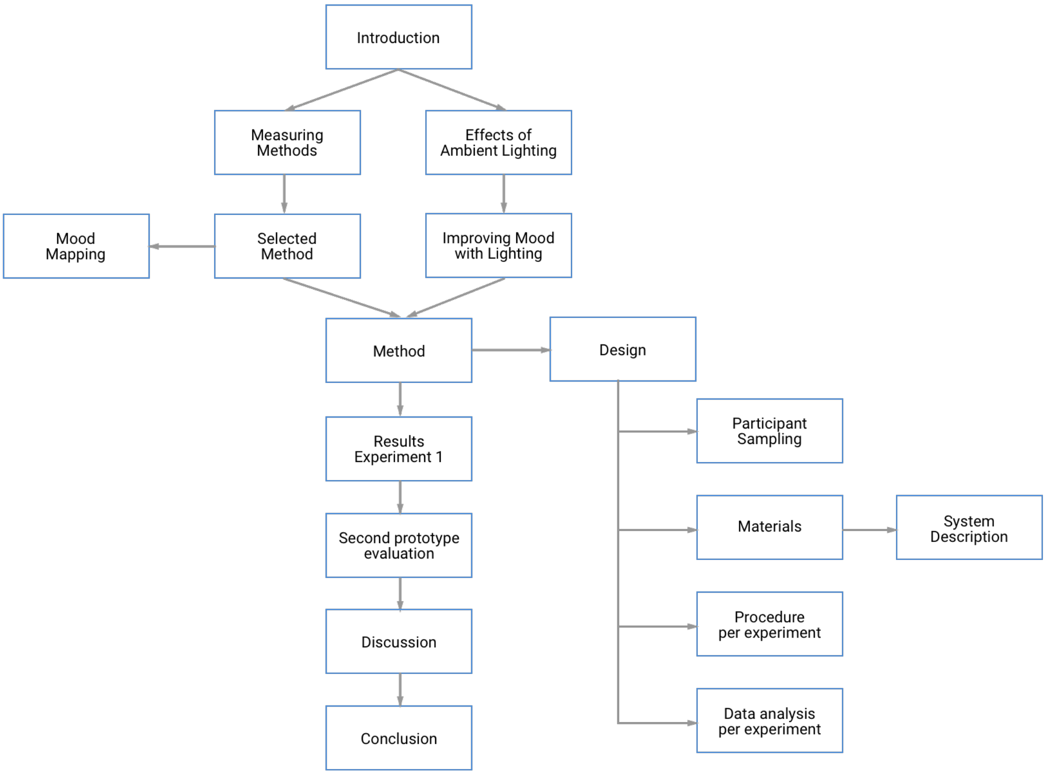


Figure 1 - Visual overview of this report

1.3. 4TU Scope

This Master Thesis is part of the 4TU Emphatic Lighting project, which focusses on developing an affect-adaptive lighting system. The project investigates how affect-adaptive ambient lighting can function inside an independent living environment for seniors (or elderly). This project is embedded into the broader context of “Empathic Computing”, which work towards an unobtrusive system that detects (negative) moods and states (and can improve them). The goal of the project, as stated on the 4TU website, is to collect under the umbrella of Empathic Computing all 4TU researchers interested in generating new knowledge in the fields of affective computing, computer vision, user modelling, sensors, wearables, internet of things, human-computer/robot/media interaction and ambient intelligence, towards the creation of empathic, caring systems (4TU Emphatic Lighting, 2017).

2. Literature review

The research area of adaptive lighting in combination with mood recognition is a wide research area in which different kinds of subjects and theories need to work together to develop a functioning system. It is a combination of recognizing and defining mood, measuring the changes and events in mood, the effect of ambient lighting on mood and the different ways of combining all this at the home of the elderly. This chapter will investigate the existing research in adaptive lighting and mood recognition, starting with the definition of mood and measuring methods and ending with the effect of (ambient) lighting on mood.

2.1. Mood and emotions

Before continuing with the literature background on mood and measuring mood, a clear definition for mood needs to be selected. There are different definitions available which explain what mood is and how it is related to other affect states like emotions and affect itself. In research by Ekkekais (2012) he explains that there are three main categories when looking at the affective domain, namely Mood, Emotions and Affect. These three terms are used interchangeably in such a way that the distinction is not always clear. Ekkekais therefore comes with the following definition of the three terms: Affect is the neuropsychological state that is accessible to person, meaning that the person experiences effect constantly in the shape of pleasure, displeasure, tension, relaxation or tiredness. Emotions are a "complex set of interrelated sub-events concerned with a specific object", meaning that an emotion is a reaction to something which can be in the shape of anger, fear, jealousy, pride and love. He shortly mentioned mood as something that is not per se about a specific thing.

Scherer continues from there by quoting Frijda (2009) for the following definition of mood: "The appropriate designation for affective states that are about nothing specific or about everything-about the world in general". This means that the biggest difference is the duration and the cause of a specific mood. A person can for example wake up feeling bad, with no clear reason, and can continue feeling bad the whole day. The difference between emotions and mood is also explained in research by Scherer (2000). Scherer starts with explaining that emotions are a notable change in functioning which is brought about by some triggering event, which last for some time and then fades away. A person who experiences emotions will notice changes in three components, namely in the physiological arousal, their motor expression and the subjective feeling. These three components together are called the “reaction triad”. Combining this information Scherer has uses the following definition for emotions: *Emotions* *are episodes of coordinated changes in several components in response to external or internal events of major significance to the organism.* With this definition, Scherer tries to compare affective states to each other in a small table. He compares Emotion with Mood, but also with Interpersonal states, Attitudes and Personality Traits. The biggest difference between mood and emotions lie in the intensity and the duration. While emotions are relatively short lived, mood lasts a lot longer and can stay unchanged for a whole day. The emotions however are more intense, because of their event focused nature and their impact on the behaviour of the person itself. Using this research from Scherer, Frijda and Ekkekais results in the following definition for mood, which will be used throughout this thesis: “Mood is the affective state that does not have to be about a specific event, is less intense than an emotion and has a long duration (ranging from parts of the day till weeks)”. During the thesis, the focus will not only lie on mood, but also on shorter affective states. The term mood will only be used when speaking of an affective state that lasts longer than 8 hours. When considering different affective states during the day, we call these emotional states. These are affective states which last shorter than moods, but at least last for an hour.

Most researchers use two measurements to define the mood a person is in. They use a valence and arousal rating. Valence says something about the pleasure or displeasure the person experiences (higher valence means a more positive mood) and the arousal ratings tells how activating the mood is (a low arousal indicates sleepiness). By combing valance and arousal into one scale, every existing or known mood can be mapped and compared to each other. Valence and Arousal were first mentioned in the research by Russel on the circumplex affect model (1980). More recent mood measuring scales take the circumplex affect model further and use only the valence and arousal ratings to indicate the mood of a person, examples of this are Pick-A-Mood and the SAM scale (Bradley & Lang, 1994; Desmet, Vastenburg, & Romero, 2016).

2.2. Mood measuring methods

There are two distinct types of mood or emotional state measuring, namely self-reported measuring and automatic behavioural measuring. The self-reported methods are based upon letting the user fill in a questionnaire or choose a specific picture from a list of pictures (or cartoon images) to self-report their own emotions and mood. The automatic method does not use the direct input of the user and focusses on the user’s behaviour instead of on what the user says he feels. Each of these two types has its own advantages and disadvantages. Self-reported methods exist for some time already and most of them are extensively tested in different types of situations, while the automatic methods are relatively new and are not yet supported with the same amount of research (especially the bio signals). Each of the different measuring methods is discussed per type in the preliminary research (Willems, 2017). The preliminary research concluded with a table that gives an overview of the researched measuring methods, see Table 1. By using the preliminary research on the research methods, a choice can be made for a suitable mood measuring method which can be used to measure the effects of lighting on the mood of the elderly. The discussed methods are facial expressions, speech and language, movement and bio signals. These methods are all automatic, meaning that they do not require any input from the user to measure the mood, in comparison to the self-reported methods discussed in Chapter 2.4.

2.2.1. Facial expressions

Face recognition is a method which is used extensively for research and in existing products like FaceReader (Van Uilenburg, Den Uyl, Israel, & Ivan, 2008) and the Affective Affdex (Affectiva, 2016). This method uses video images to detect facial expressions, which are then matched to a specific emotion or mood. While the implementation of this method can be quite fast, it requires the user to place camera's all around the house. The elderly that live independently are able to move around their home and do not always sit in the same spot inside their living room, making it harder to record their face. The data of multiple camera's need to be combined to get a real-time emotional measurement of the elderly's mood, which makes the system more complex and requires a more extensive setup in the living room of the elderly. Another disadvantage of these cameras is the idea that you are being watched, when you constantly have cameras around you that are recording your face, but also anything that happens inside your living room.

	Example Devices	Intrusiveness	Output Data	Use case examples
Bio Signals	Empatica E4 Feel, XOX, MUSE, Emotiv insight PIP, Spire	Low, the system will need to record the bio-signals on the body. It can do this this by a simple wristband making it less intrusive.	- Raw data for each time frame - One of the previously classified emotions	- Devices that want to measure mood and emotions during activity
Face Recognition	FaceReader Affective Affdex	Medium, it uses cameras to record your face. It requires a lot of cameras to always measure the emotions.	- Raw data for each time frame - Facial expressions like smiles and frowning - One of the six facial expressions	- Academic research into what people think of products or devices - Controlled environment research - Marketing purposes
Speech and Language	Beyond Verbal audEERING	Low - Medium, microphones can easily be placed in the living room, however the elderly who live alone do not have full conversations when they are alone in the room.	- Raw data for each time frame - Negative or Non-negative classification - Acoustic, Lexical and Discourse information	- Call centre dialogs - Virtual agent conversations - Marketing dialogs
Movement	Bellabeat, Lief	Low - Medium, the system needs to measure or get an image of the whole body of the user, therefore it needs multiple camera's around the room.	- Raw data for each time frame - Classification information for four emotions	- Measuring multiple persons at the same time
Self-Reported Tests	SAM, PANAS POMS, VAMS Pick-A-Mood Affect Grid	High, you need to complete a long test or do multiple short ones to give a good indication of your mood.	- A mood every time the test is conducted - Extensive analysis of the answers	- Academic research into what people think of products or devices - Controlled environment research

Table 1 - Overview of the mood measuring methods, (Willems, 2017)

2.2.2. Speech and Language

Speech and Language mood measurements use the acoustic, lexical, and discourse information to measure the positive or negative affect within the speech of the elderly (Lee & Narayanan, 2005). There are already products that can be used to measure the affect within speech which could be implemented into an emphatic lighting system, but this only works when there are conversations within the living room of the elderly (Beyond Verbal, 2017). Unfortunately, this is not always the case; one of the biggest reasons of the negative feelings at the elderly is loneliness. This does not mean that there are not visits to these elderly, but it does mean that the do not have a conversation on a regular basis, making it not the right choice for this project.

2.2.3. Movement

Movement is a mood measurement method that focusses on the movement of a (group of) person‘s body (Crane & Gross, 2007). This type of mood measurement is mostly used to measure the mood or emotions of more than one person. When implementing the movement measurement at the home of an elderly person it would require them to move around a lot, or at least more the upper part of their body while sitting. This is not something which happens a lot when they are for example watching the television. Thereby another disadvantage is, like with the facial expressions method, having a lot of cameras around to house to track the body movements, which can again give the elderly the idea that they are being watched.

2.2.4. Bio signals

A less intrusive affective state measurement method uses bio signals. Measurements via bio signals use a combination of signals, which consist out of electrodermal activity (EDA), heart rate (HR), heart rate variability (HRV), accelerometers, skin temperature and the time. In the past, the measurements of bio signals were done by placing sensors on the fingers (with some gel in between) and have them wired to a computer, but with the introduction of wristbands that can do the same it has become easier to implement this in an autonomous system. By using bio signals the user is not restricted in his or her movement and it can even measure the signals outside the living room, giving a better overview of the mood during the day.

The biggest disadvantage of using bio signals for affective measurements is relative novelty of the wearable technology. Like in the 4TU research most researchers use skin conductance to indicate arousal. When the researchers used for example, a specific lighting setting, the skin conductance levels of the participants' rise, which the researchers explained as an increase in arousal. Picard also investigated the influence of mood and emotions on the human's electrodermal activity (2015). In the research by Picard it shows that there is not one single emotion or event that triggers electrodermal activity or arousal, but that it can happen as a reaction to a lot of things, for example stress, excitement, fear, pain, anticipation, events, startle/orientation or emotional engagement. By combining the EDA information with other bio signals it is possible to detect more specific emotions, however each combination works differently and might differ per person. The electrodermal activity, for example, may vary depending on the state of the sweat glands in the skin. When the state of the sweat glands start to change, for example when you start to sweat a little, it is a direct indication that the person is aroused in a psychological or physiological way. But this state might differ per person, while one person will start to sweat a lot when for example in doubt, another's sweat glands might not respond at all.

2.2.5. Conclusion

Comparing each of the existing methods for mood detection it becomes clear that measuring the affective state via bio signals has more advantages than the other measuring methods. The biggest reason for this is the use case for desired system. In this system, the elderly need to be able to move around their house freely, while being tracked by the system. This can be implemented using some of the other methods as well, but that will require a bigger setup for the system (for example more cameras to record most facial expressions). Existing products likes like the Feel and the Empatica E4 can be used to get a good overview of the bio signals of the user, and are not limited to camera positioning (Willems, 2017). Unfortunately, the Feel wristband is not yet available, making the Empatica E4 the only option that measures all five bio signals at the same time.

2.3. Empatica E4

The Empatica E4 is a smart wearable which monitors different physiological signals which can be used real-time (Garbarino, Lai, Bender, Picard, & Tognetti, 2014). It has a combination of sensors, namely: Heart Rate Variability, Blood Volume Pulse, Accelerometers, Electrodermal Activity, Skin Temperature and an internal clock. The Empatica E4 is a wristband which uses Bluetooth to stream its data real-time to a smartphone or tablet which can upload the data to Empatica's cloud service. This chapter will shortly discuss the individual measured bio signals and will then go into mapping the bio signals to existing affective states.

2.3.1. Physiological signals

When people are scared or frightened, they do not only notice this emotionally, but they also notice changes to their bodies. We, for example, start to sweat, our breathing becomes rapid and our muscles tense (Haag A. , Goronzy, Schaich, & Williams, 2004; Kandel, Schwartz, Jessell, Siegelbaum, & Hudspeth, 2000). These effects have in common that they are all mediated by the autonomic nervous system, according to Haag et al. These body reactions can be monitored and measured, which are then named the humans bio signals. These measured signals can give insight into the affective state of the user when they are measured correctly. Each of the E4's sensors has a unique bodily reaction or physiological response that it measures (Haag A. , Goronzy, Schaich, & Williams, 2004).

Heart Rate Variability. The heart rate is used to determine the heart rate variability (HRV). A low HRV can indicate a state of relaxation in comparison to a state of stress or frustration, which is indicated by a high HRV (Haag A. , Goronzy, Schaich, & Williams, 2004).

Blood Volume Pulse. The blood volume pulse (BVP) is a measure that can indicates the amount of blood which is running through the blood vessels of a person. This can be used to measure the vasoconstriction and the heart rate (Haag A. , Goronzy, Schaich, & Williams, 2004).

Skin Temperature. Skin temperature indicates the temperature of the surface of the skin. When the body and the muscles are tense, they will contract the blood vessels, making the skin temperature a little lower (Haag A. , Goronzy, Schaich, & Williams, 2004). This can give a good indication of the muscle tensions, but unfortunately it is a relatively slow indicator of changes in the emotional state. Thereby it is influenced by the external factor temperature, which should be considered when using the electrodermal activity signal.

Electrodermal activity. Electrodermal activity (also called skin conductivity) measures the conductivity of the skin, which can increase when the skin gets sweatier. The electrodermal signal can indicate the amount of stress and indicate emotional arousal or at least an emotional response (Taylor S. , et al., 2015; Empatica Inc., 2016). Like skin temperature, electrodermal activity is also influenced by the external factor temperature.

Accelerometers. Accelerometers are used to measure the bodily movements. This can be used to for example explain the difference in bodily temperature or electrodermal activity, because when a person works out those two measurements will also increase (Empatica Inc., 2016).

2.3.2. Mapping physiological data to existing affective states with Machine Learning

When measuring each of the five physiological signals stated above, there is no information about the actual mood or affective states yet. It is necessary to first define a method to map the output data coming from the five sensors into specific affective states. Unfortunately, there does not exist a perfect bio signals mapping methodology. This has two reasons: First, it's a relatively new research area. Second, each person has his or her own response to emotions and mood, a so-called bio signals baseline, making it impossible to create one map which fits perfectly to each person (Villon & Lisetti, 2006; Picard, Vyzas, & Healey, 2001). According to Picard et al. (2001) there are several problems when you want to measure the baseline affective state of the user. First, there is almost no way of knowing whether the person was truly in a specific emotional state which is needed to begin a test. Thereby the user can be irritated by something which he or she remembers suddenly, but has nothing to do with the experiment itself. Another option is to ask the person how he or she feels, but this depends on their emotional awareness and might differ per affective state and person.

In a research by Jang et al. (Jang, Park, Kim, Eum, & Sohn, 2014) they focus on analysing bio signals classification using different types of machine learning algorithms. They aim to classify six emotions (joy, sadness, anger, fear, surprise and neutral) from multi-channel bio-signals. They do this by measuring the physiological responses in electrodermal activity, skin temperature, electrocardiograph and photo plethysmograph of 300 participants after they induced the required emotions. They conclude that the Naïve Bayes algorithm performs best with a result of 53.9%. However, this cannot be applied to a real system yet according to Jang et al. Another machine learning approach to detecting emotions is done by Gouizi, Reguig and Maaoui (2011), who focus on six different emotions (joy, sadness, fear, disgust, neutrality and amusement) and use a Support Vector Machine to classify the bio-signals to the six emotions. In their experiments, they get a general recognition rate of 85% for the six emotions. In an older research by Haag et al. they use bio-sensors to recognize arousal and valence in the emotions of the users (Haag A. , Goronzy, Schaich, & Williams, 2004). Haag et al. use a neural net classifier to recognize the arousal and valence and obtain accuracy rates of 96.6% for arousal and 89.9 for valence.

There are also approaches in which the researchers do not investigate how the bio signals can indicate a specific emotion or mood, but how it can indicate emotional arousal. The most used algorithm to do this is the EDA explorer, which is made freely available through the web by Taylor et al. (2015). This algorithm uses machine learning to look for features in an EDA signal to find natural skin conductance responses or peaks. Other algorithms can also be tested to detect peaks in the EDA signal, a more basic algorithm is the smoothed z-score algorithm (Jean-Paul, 2014) which functions without machine learning. This algorithm, discussed on StackOverflow, is not developed specifically for an EDA signal, but is focussed on real-time data and peak detection nevertheless.

2.3.3. Single subject physiological profile

Another approach to the mapping of physiological data is discussed in research by Picard et al. (Picard, Vyzas, & Healey, 2001), in which they approach the mapping by following a single-subjects over many weeks of time and recorded their bio signals during different parts of the day. They chose to follow a single subject because some forms of emotions are not only person-independent, but also have different interpretations across cultures. By using only one person, Picard et al. hope to maximize the chance of getting consistent measurements for each emotion. The method used can be used for other subjects as well, the results are subject-dependent which makes them less useful for the machine learning algorithms. By following the single subject for a couple of weeks and having daily measurement moment they achieved a classification accuracy on eight classes of emotions of 81%.

2.4. Self-reported mood measuring

While the research into bio signals is currently growing very fast, it does not have the perfect results (yet) when it comes to mapping the measurements onto existing mood states. There are different researchers that have developed machine learning based algorithms that use the big amounts of data. However, machine learning algorithms are not always ideal when it comes to measuring moods and emotions. First, these algorithms take more time to set up, meaning that it needs time before the algorithms can translate a specific person's physiological data into mood or affective states. Second, these algorithms are harder to recreate, meaning that they cannot be as easily implemented as other system. An example of another is the one used by Kuijsters et al. (2015). By using only the heart rate and skin conductance responses, they investigated the possibility to get insight into the arousal levels of the participant's mood. This makes it possible to develop a first version of the emphatic lighting system without using the machine learning algorithms and bigger sources of bio signal data. To do this, there needs to be another measurement method which can be used to decide the valence rating of the participant's mood. In the preliminary research, there are different types of self-reported mood measurements discussed (Willems, 2017). These mood measurement methods can be used without a lot of effort and only require the user to answer the given question(s) to map their mood. There are two types of self-reported mood measurement tools, the first uses a questionnaire to let the participant answer questions about his or her mood and the second uses a visual questionnaire of one or more questions. The visual questionnaire takes a lot less time in comparison to the questionnaire type because it only requires the participant to select on image. The visual questionnaire is less precise in defining the mood of the participant and relies more on the participant's input, while the longer questionnaires use specific questions to define the user's mood. Because of the speed of a visual self-reported method, the choice was made to use a visual self-reported mood measurement tool. In the preliminary research, the SAM scale, Pick-A-Mood, the Affect Grid and VAMS are discussed and compared. All four are verified to measure the mood of a participant, making the choice more a personal preference. In the end, the Pick-A-Mood scale was chosen, which is the newest of the four visual self-report mood measurement methods. In comparison to the other methods, Pick-A-Mood combined both the valence and the arousal dimension of the participant's mood into one choice. This makes it faster for a participant to select his or her mood, because it only takes one step in comparison to for example the SAM scale which takes two steps.

2.4.1. Pick-A-Mood

Pick-A-Mood is a fast-self-reported mood measurement scale. Pick-A-Mood is character-based pictorial score for the expression and measurement of mood (Vastenburg, Romero, & Desmet, 2016; Desmet, Vastenburg, & Romero, Mood measurement with Pick-A-Mood: Review of current methods and design of a pictorial self-report scale., 2016). Pick-A-Mood uses a visual way of expressing mood. The users are presented with four main mood categories, namely Excited & Cheerful (for energized-pleasant); Irritated & Tense (for energized-unpleasant); Relaxed & Calm (for calm-pleasant); Bored & Sad (for calm-unpleasant). By only giving the participant limited choices they speed up the process of mood measuring. The participant has the choice between one of the eight cartoon characters. Each character expresses a different mood, which in turn represent one of the four main mood categories. The mood the participants chooses reflects his mood at that given moment. When done multiple times the Pick-A-Mood gives an overview of variation in mood at the user, making it more useful to recognize changes in the mood of the participant. The visual representation of the moods can be found in Figure 2.

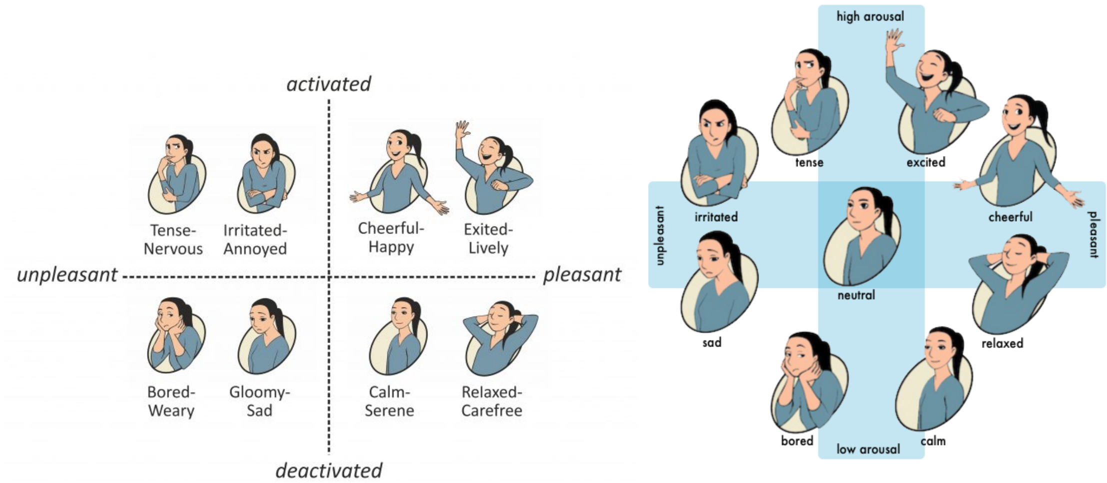


Figure 2 – Two versions of the eight mood states expressed in Pick-A-Mood

In the Pick-A-Mood manual the researchers behind the visual scale explain how to use Pick-A-Mood in new research (Desmet, Vastenburg, & Romero, 2016). They advise to use the eight images in one selection process, meaning that you will show the images all at once so that the user can compare them to each other. Thereby the choice between the different characters (female, male or robot) is a personal choice, because according to the validation research of Desmet et al. (2016) there is no character-effect in the resulting mood reporting. The two visual representations from Figure 2 differ in the fact that one uses a neutral state and the other does not. It is not necessary to use a neutral state to measure the mood states, but you can implement one if it is needed for the specific research. When doing so the researcher should keep the clear design and have the neutral state really at the middle of the other states (like the right image with the blue cross).

2.4.2. Alexithymia

To use a self-reporting system like Pick-A-Mood during an experiment or in a system there is one condition which needs to be ruled out, namely Alexithymia. Alexithymia is the inability of a person to identify and describe emotions about him or herself (Sifneos, 1973). Alexithymia is something which occurs at approximately 10% of the general population and is known to co-occur with several psychiatric conditions (Taylor, Bagby, & Parker, Disorders of Affect Regulation: Alexithymia in Medical and Psychiatric Illness, 1999).

One way to rule out people with Alexithymia is to test a user beforehand with the Toronto Alexithymia Scale (TAS-20). The goal of the TAS-20 is to measure if a person has difficulty describing or identifying emotions and if the person is used to focus their attention externally (and not internally) (Taylor, Ryan, & Bagby, 1985; Association for Contextual Behavioral Science, 2017). The TAS-20 is a self-report scale which consists of 20 items, which each use a 5-point Likert scale from 1 till 5. After filling in the TAS-20 scale, the user gets a score between the 0 and 100 with a cut-off scoring: a score between 0 and 51 means non-alexithymia, a score between 52 and 60 is possible alexithymia and a score above 61 indicates alexithymia.

2.5. Lighting and ambiences

Light and ambient lighting can influence persons in a wide range of ways, from becoming happy when seeing the sun to a specific shade of red that reminds you of your first love. Light itself is an electromagnetic radiation within a part of the electromagnetic spectrum, but the words light and lighting focus mostly on the visible light which has a wavelength in the range of 400 – 700 nanometres (between ultraviolet and infrared which we humans both cannot see) (International Commission on Illumination, 1987). Light exists out of several properties, of which hue (or the wavelength), brightness and saturation are the most important ones for this research. Hue is the property that gives light its colour, meaning that if the wavelength of the light is between the 620 and 645 the light will have the colour red, while a wavelength between the 460 and 490 will have the colour blue. Brightness is the property that describes the intensity of the light. Most lightbulbs and other light sources use the lumen scale to show how much light the user can expect from the light. Saturation focusses on the how the colours look, meaning that some colours can appear more faded than other. This means that if the saturation increases, the colour will become (for example) a purer red, while if the saturation decreases the red becomes less pure and more washed-out to white.

Lighting in the shape of light bulbs (in stores) are mostly expressed by two units, namely lux (lx) and colour temperature (K). The colour temperature of lighting says something about the wavelength of the light. It directly influences the wavelength and therefore the colour of the lighting. For example, lighting with a colour temperature over 5000 K are cool colours (blue and white), while lighting with low colour temperatures between 2700 – 3000 K are called warm colours (yellow and red) (MacEvoy, 2015). Lux is the unit of illuminance and is equal to one lumen per square metre. This means that the amount of lux indicates how much of the visible light is present for the human eye. This means that for example a moonless, overcast night sky has 0.0001 lux, an office building has 160 – 400 lux and full daylight gives 10.000 to 25.000 lux of illuminance (Schlyter, 2017; Pears, 1998).

2.5.1. Biological and Psychological level

In the preliminary research, we distinguish two types of lighting influence, namely the effects at a biological level and the effect at a psychological level (Willems, 2017).

Biological level

A direct biological effect is the amount of released melatonin in the body that can change when a person is exposed to bright light (Lewy & Sack, 2009). When the melatonin levels change, it will influence the circadian rhythm, which can cause things like a sleep disorder or mood changes (Boyce & Barriball, 2010; Bedrosian & Nelson, 2013). Researchers continues with this information and looked at the effect of lighting on the melatonin levels. They proved that the melatonin levels are lowered a lot when exposed to blue light, are slightly lowered when exposed to green light and almost does not change at all when exposed by red light (Thapan, Arendt, & Skene, 2001). This means that the amount of light with a short wavelength (like blue light) increases the alertness of the person and therefore is more arousing than green light, which in turn is more arousing than red light.

Psychological level

Not all lighting influences people on a biological level only, it can also influence a person on a psychological level because of association with past experiences. In opposite to the biological influence, red cards are more arousing than blue cards because of the biological influence (Yoto, Katsuura, Iwanaga, & Shimomura, 2007). This is because red is connected to past experiences; red is mostly used for warning signs, while blue is associated with more relaxing memories and blue skies (Kaiser, 1984). Multiple researchers agree with Kaiser and produced research that has the same results (Küller, Mikellides, & Janssens, 2009; Ali, 1972).

Combing Psychological and Biological influences

Not only the colour of the lighting influences the mood, but also the other aspects (saturation and brightness) have an influence on the mood. Different researchers have considered the difference between aspect, including Valdez et al. who argue that the saturation and brightness of the light influence the mood more than the hue of the light (Valdez & Mehrabian, 1994; Mikellides, 1990). They argue that the brightness is directly connected to the arousal and valence ratings, while the saturation only increases the valence rating (when it does not get too saturated). The mood is also influenced by the appraisal of the lighting by the users themselves. When a person judges the lighting to be just right his self-reported mood would increase, while his self-reported mood would decrease when the light was too bright or too dim.

2.5.2. Ambient Lighting

The found outcomes are mixed (between biological and psychological influences) and while they do show the high potency of influencing mood with lighting, they do not give a clear answer to the question which lighting should be used to improve the mood of the elderly. Kuijsters et al. add to this that the mood is not only influenced by the lighting, but also by other environmental factors (temperature) and personal preferences and already existing mood states (Kuijsters A. , Redi, de Ruyter, & Heynderickx, 2015). Kuijsters et al. argue that the perception of the atmosphere has the biggest influence on the mood. In a different study by Kuijsters, Redi, Ruyther, Sautiëns and Heynderickx (2014) they investigated how ambiences can influence (and improve) the elderly's wellbeing. They created two different ambiences which would counteract the two negative moods, namely anxiousness and sadness. They created these ambiences by focusing solely on the psychological effects of coloured lighting.

To create the required ambiences, they used the perception of the ambience, for which they rely on the concept of atmosphere. Atmosphere is defined by Vogels as the experience of the surrounding in relation to ourselves, through the perception of external elements and internal sensations (2008). Meaning that the atmosphere has the potency to change the affective state or the mood of the people experiencing it. Vogels mapped the perceived atmosphere of an illuminated room in four dimensions, namely cosiness, liveliness, tenseness and detachment. Based on these four dimension Vogels developed a questionnaire to measure the perceived atmosphere. Using this measurement tool several studies have been conducted on atmosphere (Custers, de Kort, Ijsselsteijn, & de Kruiff, 2010; Vogels, de Vries, & van Erp, 2008). This tool revealed the following perception of the atmosphere:

- Warm white light (2800 K) is perceived as cosier and less tense in comparison to cold white light (6000 K).
- Increasing the illuminance from 40 lx to 400 lx resulted in a less tense, less cosy and a livelier atmosphere.
- There is a negative relation between brightness and cosiness.

Kuijsters et al. (2014) argue that the perceived atmosphere can change the mood of a person in the room in the direction of the affective state of the atmosphere. They use as main argument that the mood is measured in the two dimensions: Valence and arousal, which is also used by Russel and Prat (1980) and seems related to the atmosphere model of Vogels. They do note that most studies are performed with young people and do not consider if ageing influences the perception of the ambience. For example, the ageing of the eye will result in a decline of the sensitivity to light. Knez and Kers also found out that older people think a room is less bright and warmer in comparison to younger people (2000). In their studies, they let lighting designers create ambiences and averaged their designs into four testable ambiences. The affective state was recognized by the younger participants, while the elderly ones did not always recognize it. To solve this, they did a photo interview with the elderly and created new ambience upon the results.

The new ambience did work, and they conclude that it is possible to create a pleasant, low arousal ambience and a pleasant, high arousal ambience for the elderly. The first ambience needs functional white lighting with a low colour temperature (red and white light) in combination with a warm coloured accent lighting. The second ambience needs white lighting with a high colour temperature (blue and white light) in combination with a cyan coloured accent lighting. Thereby they concluded that the elderly do not like colour pairs and prefer only one colour in the accent lighting.

In a follow-up research by Kuisters et al. (2015) they set out to verify if the preferred atmospheres do indeed have influence on the mood of the person inside the room. To do this they induce two negative mood states: Anxiety (negative valence, high arousal) and Sadness (negative valence, negative arousal). They combine these two states with two opposite atmospheres, namely cosy (positive valence, low arousal) and activating (positive valence, high arousal). By testing 15 minutes per participant they measure the effectiveness of the atmospheres, using the SAM scale and bio signals. The test resulted in a clear improvement in the mood of the elderly over the recorded 15 minutes. This means that asking the elderly how they perceive the atmosphere is an effective method to find the light settings to increase the mood of the elderly.

2.5.3. Phillips Hue

One way to create ambient lighting is by using Philips Hue. Phillips Hue, introduced in 2012, is a light bulb which can be controlled remotely via an iOS or Android app (Stern, 2012). The idea behind the lamp is that you can play with the colour and brightness in different rooms within your home to match your mood or let you wake up by slowly turning on the lighting in the house. The lamp can be easily placed in existing light bulb spots and only needs a hub to work via your smartphone or tablet. However, there are existing homemade projects that combine Phillips Hue lamps with basic mood recognition software to make it change colour depending on the emotions of the people in the room. Phillips Hue originates from the Philips Ambilight, which is ambient lighting created to improve the television watching experience. The Ambilight uses backlighting to make the television images more intense. The processor of the Phillips Hue is also used in the research by Kuijsters et al. to create the different ambiences (2014).

The Philips Hue light bulbs and API do not use the Lumen and Kelvin based system to change colour, but they use a combination of four components, namely brightness, saturation, hue and colour temperature. The lightbulbs range from 340 lumens at 2000 Kelvin to 806 lumens at 4000 Kelvin, while they can also reach a higher Kelvin with a lower lumen (550 lumens at 6500 Kelvin). There is no actual table or guide about how the Philips Hue settings can be translated into Kelvin and Lumen values, therefore the brightness, saturation, hue and colour temperature will be reported when the Philips Hue light bulbs are used.

2.6. Inducing mood

With the research on mood and mood recognizing, there is one aspect that is used in a lot of related literature, namely the induction of mood. The induction of mood focusses on putting a person in a specific, researcher chosen, mood, by exposing the person to a (series of) media that is designed to have a clear influence on the person. Inducing mood is generally done to measure the effect or impact of mood on other processes (like creativity), but it can also be used to measure the impact of for example lighting on the mood. In this chapter, different methods for inducing mood at the participants are investigated.

Moss (2016) investigates the different existing methods which are used by other researchers. There is a wide range of different emotional stimuli which can be used to induce mood, according to Moss, such as (uplifting) music, images, critical feedback and forming emotional memories or (hypothetical) events. This information can also be used to get measurements for basic mood states, like angry and happy. When inducing a mood in the right way, the user can then look at the bio signals and see how they correlate with each individual mood. This might be useful when trying to create a baseline for an individual person. There are a couple of mood inducing sets developed in other research, namely the IAPS photo set, the Gross and Levenson movie set and a combination of multiple stimuli.

IAPS photo set

The IAPS photo set can be used to induce mood and is for example used in the research by Haag et al. (2004; Lang, Bradlet, & Cuthbert, 2001; Center for the study of Emotion and Attention, 2001). This photo set uses over 800 pre-classified photographs, which each have a valence and arousal level. There are photo's in the set which can be used to normalise the mood, which then can be follow up with photographs with either a higher valence or arousal (or both). Some of the photographs can have a disturbing effect according to Haas et al. making it necessary to increase the arousal levels progressively to minimise the disturbing effects. Thereby they also showed the high arousal, negative valence photographs last, because they were found to be disturbing to let the users return to the normal resting state after seeing them. In the IAPS set each photo is indexed with a valence and arousal rating. The valence and arousal ratings range between 1 and 9; for valence 1 equals very negative and 9 very positive and for arousal 1 equals very low arousal and 9 equals very high arousal.

Gross and Levenson movie set

In the 4TU empathic lighting project (Kuijsters A. , Redi, de Ruyter, & Heynderickx, 2015) they chose to use a mood induction procedure based on viewing movie excerpts. They used two short film segments selected from the database of Gross and Levenson (Gross & Levenson, 1995), which would induce sadness and anxiety. This database was created to provide a set of films that would elicit each of eight emotional states (amusement, anger, contentment, disgust, fear, neutral, sadness, and surprise). They concluded with 16 films that successfully elicited the first seven emotional states and to a lesser extent the eight state, fear.

Combining foreground and background inducing methods

In research by Mayer, Allen and Beauregard (1995) they investigated the difference in foreground and background mood inducing methods. They conducted three user tests in which they combined background music and guided imagery vignettes. Background music and imagery vignettes were selected which have high ratings on the target mood and low ratings on the non-target moods. After the three conducted tests, they concluded that the combination of the foreground and background method was reliable and did indeed induce on of the four moods (happy, angry, fearful, and sad).

2.7. Target group

While investigating the different aspects of mood recognition and Emphatic Lighting it is hard to not discuss the influence of the target group. Almost each specific part of the research depends on the user of the product. For example, face recognition cannot measure the mood constantly when the user moves around a lot. The target group for this project are the elderly who live in an assisted living home. The elderly that live alone in assisted living homes often experience negative emotions or moods, such as gloominess due to the distance from their families or anxiety when disoriented (e.g. due to dementia) (4TU Emphatic Lighting, 2017). This chapter will discuss the target group and how they might respond to Empathic Lighting and is based upon the research of the target group in the preliminary research (Willems, 2017).

2.7.1. Interviews with caregivers

In previous research by the 4TU Empathic Lighting research group they focused on which things should be considered when designing adaptive lighting to improve the elderly's mood (Huldtgren, Katsimerou, Kuijsters, Redi, & Heynderickx, 2015). As part of the design process Huldtgren et al. conducted interviews with caregivers from different kinds of care settings (day care, stationary care and home care) to gather requirements for the design of a future system. For the interviews, they started out with caregivers in care homes located in Delft and caregivers from a care home specialized in people with dementia in The Hague. During the interviews, they decided to expand the study by also interviewing caregivers from an organization offering independent living units, and comparing afterwards how the design requirements would differ for each care setting. To give the interviewees an idea about how adaptive lighting could be used to change the mood of the elderly they showed the interviewees two examples of lighting in a living room, one cosy and one activating setting (see Figure 3). At the analysis of the interviews Huldtgren et al. identified recurring ideas and themes, which they categorized in higher level themes, namely Mood and Emotion, Mood in seniors with and without dementia, Mood recognition and Influences on mood.

Figure 3 - The two examples of lighting used in the interviews: (a) cosy, (b) activating.

The interviewed caregivers identify mood and emotions mostly by their duration. Emotions are a reaction to something that happens, while moods last a longer period. The caregivers know that moods can last days or even more than a week, but when a gloomy mood for example exceeds several weeks the caregivers would consult a doctor. In the case of dementia, the moods are either more negative more often (mild dementia) or the moods change more quickly (severe dementia). One big consideration is the fact that the caregivers for dementia patients talk about single cases, which means that an automatic mood recognition system will have a hard time recognizing these emotions. This might mean that the system needs to be tailored to a specific case.

Mood recognition is something that each caregiver does when he or she enters the room. The mood of the patient changes the way the caregiver interacts with the patient. One thing all the caregivers mentioned is that the longer they know the patient the easier they can recognize the mood state, while this is almost impossible with new patients. The two most important aspects which the caregivers use to recognize the mood are the facial expressions (the eyes) and the voice of the person. The caregivers mainly focus on the negative moods, in which they recognize Gloomy/Depressive, Scares/Nervous and other moods. The caregivers talk about depression when they refer to a medical condition which can be treated and diagnosed by a doctor, while gloominess is something similar but cannot be connected to a medical condition. The biggest difference between the two is that with depression the patient is more withdrawn, *they are more focused on the inside, introverted.* The scared of nervous mood is something which happens mostly at the dementia patients. They recognize this by observing that the patient wants to move or when he or she cannot focus on the conversation. Other negative moods are almost never observed, and if they are observed they are almost always connected to a specific disease.

The mood of the elderly depends on mostly external factors, namely loneliness, weather, time of day, sound, light and smell and two internal factors illnesses and memories of events. The most important external factor to lead to gloominess is loneliness, according to the caregivers. There are a lot of elderly that sit alone when the caregivers leave, and are alone four days a week. Thereby the elderly have more depressing feelings in the morning when they still have the whole day in front of them, while in the evening they are much calmer. Other external factor such a weather does not influence the mood directly, but limits the movement of the elderly which might influence their mood. Light in comparison to sound and smell has the most positive effect on the mood according to all interviewed caregivers. They do not name a specific reason for this.

Huldtgren et al. conclude their design considerations with a mood model which displays which factors influence the mood and how this is recognized by the caregivers. This mood model is called the “Senior Mood Model” and can be seen in Figure 4. Overall the caregivers’ reactions to the system were diverse, they were positive towards using light to improve the mood, but they think that it might not work with patients who suffer from dementia (*it might bring feelings of anxiety to the surface*).

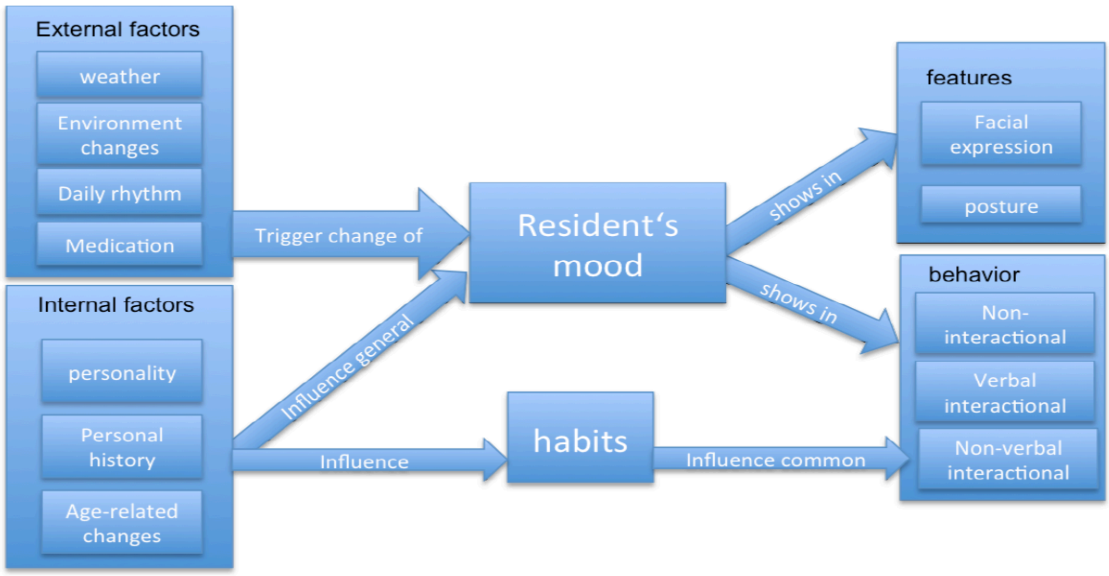


Figure 4 - Senior Mood Model by Huldtgren et al.

Huldtgren et al. also discussed the different measurement methods with the caregivers. A system with camera or sensors should be agreed on by the patients and the family, and in that case that only half of the people would agree to place the sensors in their home. They also bring up the discussion about independent living, because patients who still live independently wants to stay in control as much as possible, meaning that they want to keep in control of the lights in their house. This makes the system a better fit to the patients who cannot live independent anymore, for example in care homes. They conclude that a good way to improve the mood is to automatically detect the mood and then give the user the choice to change the lighting or not.

2.7.2. Caregiver overview and persona

By using the interviews Huldtgren et al. did with the caregivers it is possible to create an overview that will sum up this chapter point wise. From the interviews the following requirements come forward:

- Caregivers know the difference between moods and emotions. They say that moods last longer, especially gloomy moods, in comparison to emotions and do not always have a clear reason. This confirms the mood definition set in Chapter 2.1.
- Caregivers focus on mostly the negative moods, because they want to improve the negative ones, which is the same goal as this research has.
- Caregivers find it easier to identify moods when they know the person better.

Caregivers use a combination of facial expressions and speech recognition to identify different mood at the elderly. They gain this ability because of their experience in the elderly care and do not (yet) use any tools for this. In addition to these requirements a persona is created, which will serve to identify the user (group) for the ambient lighting system. The persona will help to define on what kind of person the system and the user experience should focus. A persona is an archetype, which means that it is used as an example for what kind of users will use the system (when finished) (Junior & Filgueiras, 2005). This persona can be used as a model of a user that will benefit most of the system. By comparing the participant(s) with the created persona, it is easier to look at the results in another perspective (and not see them as the ground truth). For this purpose, the persona of "Jannie van Vlissen" was created and is displayed in Table 2.

	Jannie van Vlissen Age: 85 Gender: Female Working status: Retired Living situation: House within retirement home
Situation	Jannie is a retired 85 years old female, who lives in an apartment which is close to the retirement home, but she does not receive care on a daily basis (yet). She has two children and four grandchildren. She tries to have contact with at least one person per day.

A day in the life	Jannie lives alone in her apartment in the city next to the village in which she has lived her whole life. She does not have a lot of friends in the retirement home and does not leave her apartment when it is not necessary. She loves to watch television or read a book, but is not as mobile as she used to be. She uses a walker when she needs to walk through the supermarket or goes outside the retirement home for a longer time. Jannie playes board games with a group of friends on Monday and gets visits by one of her children on Tuesday and Saturday. On Wednesday, she visits the game evening at the retirement home (where they play mostly bingo). On Friday she eats in the canteen of the retirement home and on Sunday she does not have a regular event.

Table 2 – A persona of an elderly person who might use the system

2.7.3. Physiological signals at elderly persons

With an elderly participant, the effectiveness of the physiological data measuring with the Empatica E4 should be checked and tested beforehand. This is because the elderly are known to have drier skin, which might influence the skin conductance (iMotions biometric research platform, 2016). When the skin is too dry it might have a skin conductivity which is too low to pick up by the E4, resulting in a EDA signal which is not useable. To make sure the E4 could measure the physiological data from an elderly person, this was tested beforehand. An elderly person (age 83) wore the wristband a whole evening. Fortunately, the data from the elderly person did not differ from the other participants who had participated in the first experiment, showing that it is possible to use the E4 to measure the physiological activity at an elderly person.

2.8. Conclusion

Concluding the literature review, there are a lot of things which influence mood recognition based ambient lighting, ranging from the method of measurement to requirements from the target user group. To be able to develop a system that can accurately measure a person’s mood and adapt the lighting on this measurement, a couple of choices will be made based upon the existing literature and technologies discussed in this chapter. In the following chapters the development of a first system will be investigated, in which (parts of) the literature discussed in this chapter will be used as a basis for the development.

3. Methodology and experiments setup

This chapter describes the method used to answer the research questions of this research. First, the design of this research is explained. Next, the participants, the materials and the procedure of the experiments are described. Finally, the data analysis is described.

3.1. Design

To answer the research questions of this research, mixed methods are used. First, an experiment is conducted to review the related and used literature from the Chapter 2, which is called the first experiment. Building on this first experiment, experiment 2 is conducted to answer the remaining research questions, including the main question.

To answer the first research question, the first experiment will record the physiological mood measuring method on the background of the user test. This EDA data will not have any influence on the first experiment, but will record the influence each part of the experiment has on the physiological data of the person.

To answer the second research question, the first experiment also focusses on how the physiological EDA data can be used to detect peaks in the arousal state of the participants. The EDA signal will be recorded and stored to be compared to the Pick-A-Mood results and the mood inducing video timing.

To answer the third research question, the second experiment will let the participant interact with the system without guidance of the researcher. The participant uses each part of the system and needs to report her mood when requested by the system. Thereby during the second experiment, the participant will be interviewed about her experience with the system and especially her experience with the changing ambient lighting.

To answer the fourth research question, the findings from related literature about mood affective ambient lighting is reproduced during the first experiment. These findings are analysed on effectiveness and on how the participants perceive the chosen ambient lighting settings. In the second experiment, the outcomes of the first experiment are reproduced in the living room of an elderly person. This setup is tested for longer periods of time to look at the effectiveness of the ambient lighting.

To answer the main research question, the results from the first and the second experiment are used. First, the first experiment focusses on testing the system's capabilities to measure the physiological data and focusses on the influence of the different ambient lighting settings on the participants' affective state. Experiment 2 uses this information to improve the system and automatically measure and improve the mood of the participant using a self-reported mood measuring tool and an ambient lighting setting which is perceived as very positive by the participant beforehand. The self-reported mood measurements, the physiological data and the experiences of the participant are then used to look at the effect of the ambient lighting on the mood of the participant.

3.2. Participants and sampling

The first experiment does not yet use elderly people as the participant, but first uses younger people to test the system and verify the found literature from Chapter 2. To determine who will be part of the first experiment, the snowball method was used. Snowball sampling is a method that selects several key participants and request them to recruit other people (Biernacki & Waldorf, 1981). These steps were repeated until the needed sample size was found. The criteria for the participants is that they do not test positive for alexithymia. This is tested by the TAS-20 test before the start of the experiment. The TAS-20 results are anonymized, meaning that the participants did not know if their data was not used because of a too high TAS-20 score. During the first experiment only one participant scored too high on the TAS-20 and this participant's data was not used. In total, 20 people participated in the user test. In total, 14 were male and 6 females. The average age of the participants is 24, ranging between 18 and 35. The participants all have the Dutch nationality. Beforehand, the participants signed a consent form which is required by the ethical committee of the Faculty Electrical Engineering, Mathematics and Computer Science at the University of Twente, which can be found in Appendix 10.1. This committee approved the setup and procedure of the first experiment.

The participant selection of the second experiment has two sides to it, namely the participant should match the persona created in Chapter 2.7.2 and the participant is recruited via the criterion sampling method. The criterion case sampling is used to select the participant that meets the predetermined criterion of importance. Three criteria were identified: the participant should live alone, like described in the persona and the participant should be able to self-report on everyday experiences, emotions and moods, and thus not have any form of Alexithymia. One participant was selected for this second experiment, because of the explorative part of this research. That way, there are opportunities to learn as much as possible about the research problem and questions on how to develop the system in the future with more possibilities.

By using the criteria described in the persona, a participant was the second used test is selected. The situation and summary of the chosen participant can be found in Table 3. The profile of the participant fits almost perfect when compared to the persona from chapter 2.7.2. She is also an elderly woman who lives alone in an apartment. The biggest difference is the location of her apartment. While the participant still does everything herself, the persona makes use of the facilities of the retirement home.

	The Participant Age: 82 Gender: Female Working status: Retired Living situation: Independent apartment
Situation	The participant lives alone in an apartment, which is not a retirement home. The apartment is in an apartment complex in which mostly people live that are retired (the ages of 60+). The participant has two sons and two grandchildren. She lives in a small village in Overijssel, the Netherlands (approx. 5500 inhabitants) in which she lived for the biggest part of her live (50+ years).
A day in the life	The participant does not have a certain daily routine, but does have a weekly routine. The daily routine is focussed on at least seeing one person a day. On Mondays, she plays a game of bridge in a big group, on Tuesdays she plays bridge in a small group of four and eats fish together with her neighbour, on Wednesday she goes to aqua gym together with a friend, on Thursday she visits her daughter in law, on Fridays her son, daughter in law and granddaughter eat at her house, at Saturday both her sons visit her in the morning and on Sunday she always spends the morning with a friend. Furthermore, she is an active iPad user and loves reading books or the newspaper, making jigsaw puzzles and watching television. The participant experiences negative moods in her daily life, but these moods do not always have a clear reason. These negative moods also depend on the week, meaning that some weeks she experiences only a couple of negative emotions or moods, while sometimes the whole week she is in a slightly negative mood.

Table 3 - Participant profile for experiment 2

3.3. Materials

To answer the first two research questions and to investigate parts of the system needed for the second experiment, several materials are used in the first experiment and second experiment. Most materials used in the first experiment are re-used in the second, but also new materials were used. An overview of these materials can be found in Table 4. A thorough explanation of each material is given in this chapter.

Material	Experiment 1	Experiment 2
TAS-20	V	V
Pick-A-Mood	V	V
Ambient Lighting with Philips Hue	V	V
Empatica E4	V	V
Mood induction	V	
Atmosphere perception questionnaire	V	V
Context mapping diary		V
The system	V	V
Living room at the university	V	
Participant's own living room		V

Table 4 - Overview of the materials used in the experiments

3.3.1. TAS-20

The TAS-20 test will be done before both experiment to test the participants for Alexithymia, which is explained in Chapter 2.4.2. The test results in a score between 0 and 100, of which a score of 52 or higher identifies the presence of Alexithymia. This test is done by using the Dutch version of the TAS-20 test developed by Taylor et al. (1985). The test gives a score between the 0 and 100, of which the participant should score below 52 to be sure he or she does not have possible Alexithymia.

3.3.2. Pick-A-Mood

The Pick-A-Mood self-reported mood measuring method as described in Chapter 2.4.1 is used to let the participants self-report their current mood or affective state. This method is used in both the experiments and in the system. In the first experiment, it is used in the system on the Nexus 6, while it is also used in the context mapping diary for each event the participant maps in the second experiment.

Prior to using the Pick-A-Mood self-report mood measurement tool in the experiments, a small test was conducted with participants to test the use of the system. After having used the Pick-A-Mood self-reported mood measurement tool, the participants reported that the tool was easy to use. None of the participants mentioned that he or she did not know which of the eight moods represented their current mood state. This shows that this is a usable and is therefore used for both experiments.

3.3.3. Philips Hue

To investigate the influence of the ambient lighting on the participant during both experiments, a set of Philips Hue lighting is used. This set consists of a Philips Hue Bridge which is connected to the system and three light bulbs. The colour and intensity of these three light bulbs can be controlled by the system.

During the first experiment, in addition to the Philips Hue also two other lighting sources are used in this experiment, namely a standing lamp and a desk lamp. These two additional lighting sources both have an incandescence light bulb, emitting a warmer yellow light. For the first experiment three lighting settings are used, that will be described in Chapter 2.5.2. All three settings use the two lighting sources and change the Philips Hue to create a different ambience or atmosphere. The overview of the three settings can be found in Table 5. These settings are also displayed in Figure 5. However, this figure does not show the settings as used in the living room, but only the direct lighting coming from the individual light bulbs.

Setting	Brightness	Saturation	Colour Temperature	Hue
Cosy	100	200	500	35000
Activating	254	200	155	43500
Neutral	150	150	155	24000

Table 5 - Overview of the used Philips Hue settings per atmosphere for experiment 1

Figure 5 - Lighting settings for experiment 1 (l.r.t.b. Neutral, cosy and activating setting)

In the second experiment, the system controls the same ambient lighting as in the first experiment, consisting of three Philips hue light bulbs and including the Philips Hue Bridge. The lighting which is already present in the living room is used, consisting out of two lighting sources which can be seen in the map of the living room displayed in Chapter 3.3.9. Two different ambient lighting settings were used, namely the neutral and the cosy setting. The neutral setting represents the lighting which the participant normally has in her living room, by making use of the Philips Hue. The cosy setting was chosen together with the participant, using the perceived atmosphere from Vogels (2008), and will be discussed in the procedure of the second experiment in Chapter 3.5.2.

To test how the ambient lighting settings are perceived by the participants, the Vogels (2008) atmosphere perception questionnaire is used in both the first and second experiment. This questionnaire is described in Chapter 2.5.2. In the first experiment, the questionnaire is used to verify the results from Kuijsters et al. (2015) and in the second experiment, it is used to select the most cosy and lively ambient lighting setting. The used questionnaire can be found in Appendix 10.2.

3.3.4. Empatica E4

In the first experiment and in the second part of the second experiment, the Empatica E4 will connect to the system via Bluetooth and put in streaming mode. In this mode, the Empatica E4 will not store the data on wristband, but will send the data real-time to the system, which will use the data for the peak detection algorithm. The E4 will not send the data real-time towards the system in the first part of the second experiment, but will record and store the data on its flash memory. This data will be uploaded using the build-in functionality, called Empatica connect.

3.3.5. Mood induction

During the first experiment, the participant will get a sad mood induced. This is because the first experiment relies on having the participants in this specific starting mood, which is used to remove as much as possible the differences between the affective state of the participants at the start of the test. By using a method that is already extensively researched and has a high efficiency, the different participants will get into a similar affective state or mood at the start of the experiment.

A sad mood has both a low arousal and low valance, which is the negative mood that occurs the most for the elderly that live alone according to the target group study. To induce a sad mood, emotion indication method by Rottenberg, Ray and Gross (2007) was used. This is an updated version of the original Gross and Levenson (1995) movie set as discussed in Chapter 2.6. There are in total three movie clips recommended to induce a sad mood in this movie set, namely the Champ, Lion King and Return to me. The emotions of these movies (Amusement, Anger, Confusion, Disgust, Embarrassment, Fear, Happiness, Interest, Sadness and Surprise) are indexed on a scale from 1 to 8. From the three recommended sadness movie clips, Return to me gives the highest mean sadness score (7.0 for males and 6.93 for females). Therefore, this clip was chosen to induce the mood of the participants.

The Return to me movie clip consists of three main parts. It starts with a positive scene in which the two main characters are dancing together on a romantic song. This scene shows that they are happy and in love. After 55 seconds, the scene changes from the dancefloor into a hospital hallway. The paramedic tells the doctors that the women was in a car accident and has head injuries. At 1:23 the man arrives homes with a bloody shirt together with a friend of his. This scene shows how much impact the accident had on the man. At 2:37 the friend leaves and the man sits down next to the door together with his dog. He tells the dog that she is not coming home, indicating that his wife or girlfriend has died. The clip ends at 3:36. There are two emotional events during the full duration of the clip, namely the moment the happiness turn to sadness (at the hospital) and when the man returns home and tells the dog his wife died.

3.3.6. Context mapping

During the second experiment, a context mapping diary is used to get insight into the emotional events that occur to the participant during the day. Context mapping is a method which can be used to gain insight into the everyday experiences, emotions and even moods (Stappers & Sanders, 2003). Most research into context mapping is focussed on mapping how people interact with (new) products (Sleeswijk Visser, Stappers, Van der Lugt, & Sanders, 2005). Designers use context mapping to get more insight in what the users need and how they might use the product. There are different tools and techniques available to map the context of the participant. Sleeswijk Visser et al. (2005) and Gaver et al. (1999) identify four elements that can be used for the mapping: a disposable camera, a workbook, a diary and postcards. This experiment requires the participant to note down all the events in their life that engage them emotionally. This can be done using either a workbook or a diary, of which the diary method is chosen. For this experiment, the participant will need to write down in the diary everything what she experienced during the day that has emotionally influenced her, which will also help the participant to think about what is happening during his or her day.

The developed diary in which the participant will mark the different events from each day, consists of different parts. First, it has the general introduction into the research. The introduction describes the goal of the research and shortly what is required from the participant. Thereby it also contains an already filled in day overview as an example. After this introduction with examples, the diary consists of the upcoming five days of measuring. Each day consists of a maximum of ten events about which the participant can write. Each day also has a general overview of the day, in which the participant can write down how he felt about his day in general. Each event consists of the time of the event, the general mood or emotion associated with the event, an open question about what happened during the event, an open question about how the participant felt during the event and a Pick-A-Mood overview. Four pages of the developed diary can be found in Figure 6.

Dagboekje

Gebruiker: ________________

Datum: ________________

Dit dagboek wordt gebruikt voor de Master Thesis van Pim Willems.

Uitleg

Voor je ligt het "context mapping dagboek". Het is de bedoeling dat je in dit dagboek alle grote evenementen opschrijft welke tijdens een dag voorkomen. De focus ligt hierbij op je gevoelens, dus schrijf vooral de dingen op die je blij, verdrietig of enthousiast maken. Hierbij kun je denken aan een wedstrijd van het Nederlands elftal waarbij ze nipt winnen, een verdrietige film, maar ook het kort spreken van een oude bekende.

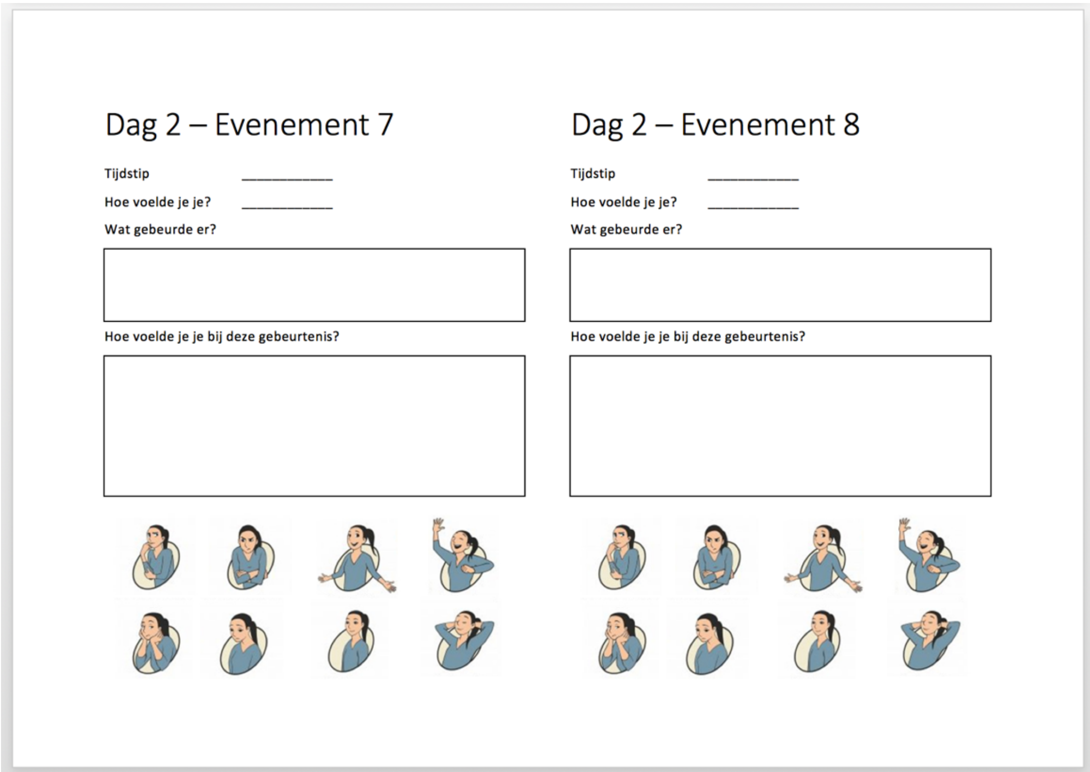
De pagina aan de rechterkant geeft een voorbeeld van hoe het dagboek ingevuld kan worden. Dit is slechts een voorbeeld, want je bent vrij om de evenementen te omschrijven hoe jij het fijn vindt.

Dit dagboek zal gebruikt worden in combinatie met de armband die je zult om krijgen. Deze armband registreert de zo genoemde fysiologische gegevens, zoals je hartslag, huidgeleiding en beweging. Door deze gegevens te combineren met dit dagboek is het mogelijk om inzicht te krijgen in wat de gegevens betekenen met betrekking op emoties en humeur.

Voor alle opdrachten geldt dat een eerlijk antwoord altijd het best antwoord is. Maak je geen zorgen wanneer je denkt dat iets niet duidelijk is, er zal naderhand nog een moment komen waarop je mondeling dit dagboek kan toelichten. Als je een vraag hebt kun je mij het altijd vragen persoonlijk of via de telefoon.

Groeten Pim

Pim Willems
Tel: 06 11568577



Dag 2 – Evenement 7

Tijdstip ________

Hoe voelde je je? ________

Wat gebeurde er?

Hoe voelde je je bij deze gebeurtenis?

Dag 2 – Evenement 8

Tijdstip ________

Hoe voelde je je? ________

Wat gebeurde er?

Hoe voelde je je bij deze gebeurtenis?

Figure 6 - Four pages of the developed context mapping diary

3.3.7. Mood controlled ambient lighting system

The main system used during this thesis is called the Mood Controlled Ambient Lighting System (to be referred to as system). This system was developed to measure the physiological data and use this data to change the ambient lighting. This system combines the physiological data measured by the Empatica E4 with the ambient lighting created by the Philips Hue. The system uses a peak detection algorithm to detect changes in the arousal state and uses the Pick-A-Mood self-reported mood measuring method to get the valence of the emotion. Hence, this section will discuss the development of this system.

Requirements

Before starting the development of the system, a list of requirements was made. This list was used to ensure that the system could handle different types of situations that were encountered during this research. These requirements were based on the literature review and the experiment design to answer the research questions.

<u>Requirement 1 - The system should connect to the Empatica E4 and receive the physiological data real-time from the wristband via Bluetooth.</u>

The first and main requirement is the need to create a connection between the Empatica E4 and the system. The system needed to connect to the Empatica E4 wristband and get a real-time stream of data from the E4. This data stream should consist of the full set of sensor data, which can be recorded by the Empatica E4. The data included the heart rate, blood volume pulse, EDA, temperature and accelerometer data. This requirement is related to the first two sub research questions, which require the system to measure the physiological data so it can be mapped to different moods.

<u>Requirement 2 – The system should be able to detect a peak in the EDA signal which indicates emotional arousal at the user.</u>

The real-time data streamed from the Empatica E4 needed to be mapped towards affective states by the system, or at least the system needs to be able to detect peaks in the EDA data. As mentioned in the literature review in Chapter 2.3.2, the system could also use a peak detection algorithm to detect changes in the emotional arousal of the user. Because of the higher difficulty of implementing machine learning algorithms, the system should be able to detect peaks in the arousal dimension first, before mapping the signals to existing affective states. This requirement relates to the second sub research question, which requires the system to map the physiological data to useable definitions of mood.

<u>Requirement 3 – The system should be able to control the Philips Hue lighting bulbs by connecting to the Hue Bridge via the API.</u>

To change the ambient lighting around the house of the user, the system should change the Philips Hue lightbulbs settings. The light bulbs are controlled via the Philips Hue bridge. The system should therefore be able to connect to the Philips Hue Bridge and change the ambient lighting by changing the individual connected Philips Hue light bulbs via the Bridge. The system connects to the Philips Hue Bridge using the Philips Hue API, which enables the system to change the lighting settings. The main research question and the second and third sub research questions require the system to change the lighting around the house to positively influence the mood of the participants.

<u>Requirement 4 –The system should have a Pick-A-Mood interface with which the user can interact to self-report his or her current affective state.</u>

The system uses peaks to detect changes in the emotional arousal state, it does not give any information about the valence of the emotion or mood. By using the self-reported mood measurement tool Pick-A-Mood the system can ask the user about the valence of his or her mood or emotion. This requires the system to have a Pick-A-Mood interface which is used by the user to pick one of the eight Pick-A-Mood characters.

<u>Requirement 5 – The system should provide the user with a GUI with which the user can interact.</u>

The system should have a Graphical User Interface (GUI) with which the user can interact. The system should give the user the option to change the lights manually. This can be done by giving the user a couple of ambient lighting states to choose from, but also by using the Pick-A-Mood interface to change the light according to his or her affective state. The use of an GUI is required by the third sub research question, and will be used to test the user experience of the participant while interacting with the system.

The device

The system will run on a Nexus 6, which uses the Android operating system. This phone provides the system the possibility to use Bluetooth and connect to a Wi-Fi network, which are required for the system. The system can also be installed on other phones or tablets running Android, but only if they have at least Android API level 25. This API level is needed to use the low energy Bluetooth connection required for the Empatica E4 Bluetooth connection.

EDA peak detection algorithm

The first two requirements indicate that a peak detection algorithm is required to be able to detect changes in the mood of the participant. The algorithm which will detect these changes, should rely on the natural peaks in the physiological signal, meaning that the peak should rise slowly and not consist out of one small peak. Boucsein (2012) provides a complete description of the characteristics of an EDA signal and refers to a EDA response that lasts between one and five seconds and has a steep onset and an exponential decay. However, this cannot be directly copied into a working system or algorithm, according to Taylor et al. (2015). Taylor et al. detect peaks with their EDA explorer algorithm using multiple parameters focussed on slopes that are not always perfect. With these parameters, they try to also remove the errors or wrong measurements that occur because of for example the movement of the sensor. In Figure 7, the difference between the natural peaks and non-natural peaks is visualized. The non-natural peaks are most of the time the result of an error in measurement, because it consists of only one or two high values and does not show an increasing slope before the peak or a decreasing slope afterwards.

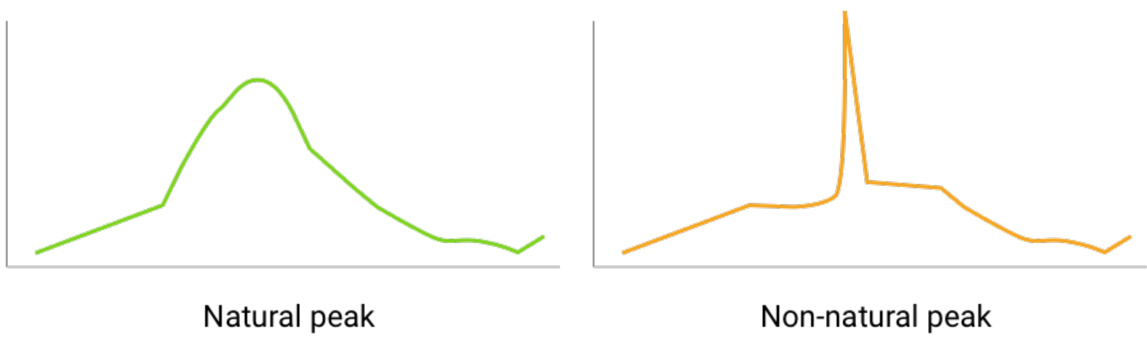


Figure 7 - Difference between natural and non-natural peaks

The peaks in the EDA signal will last for seconds, sometimes multiple minutes before the signal decreases again. Therefore, it is impossible to use traditional peak detection methods, which mostly focus on one maximum or minimum. Another important part is the fact that the data is live streamed and therefore updated every fourth of a second. This makes it impossible to look at a derivative, for which a function is required beforehand. Two existing algorithms were discussed in the literature review in Chapter 2.3.1 and will be described in the next paragraph.

EDA Explorer

Research of Taylor et al. (2015) describes the development of a machine learning algorithm for automatically detecting EDA peaks and provide an empirical evaluation of the classification performance of this algorithm. The authors encoded the machine learning algorithm in a web-based version which is free to use with anyone's data (designed for data from either the Empatica E4 or the Q Sensor by Affectiva) (Taylor, S. et al. 2015). This web-based algorithm does not only detect peaks in recorded EDA data, but is also able to filter noise out a signal and label Epochs. Taylor et al. (2015) focus on pre-recorded epochs (periods) within EDA signals with a length of five seconds. The authors concluded with a classification algorithm that uses the amplitude, the mean, the first and second derivative to detect peaks in the EDA signal.

For the EDA explorer algorithm, different kinds of settings can be changed to detect different kind of peaks, namely the minimum amplitude, the offset, the filter frequency, the filter order, the max rise time and the max decay time (Taylor S. , et al., 2017). The minimum amplitude set the minimum value the EDA signal needs to have before it can be counted as a peak. The offset is the number of second the derivative must be positive before a peak and negative after a peak. This offset is used to detect a natural peak. The filter frequency is a cut off frequency in Hz for the EDA signal. The filter order is the number of poles in the filter. The higher the order, the steeper the cut off on the filter. The max rise time is the maximum number of seconds before the peak reaches its highest point. The max decay time is the maximum number of seconds before the peak decays into 50% of the amplitude.

Smoothed z-score algorithm

The smoothed z-score algorithm focuses on detecting peaks in real-time data. This algorithm is described and developed by Jean-Paul (2014). The algorithm is based upon the number of standard deviations the new input is away from the moving mean. According to the author, the algorithm is very robust because "it creates a separate moving mean and deviation in such a way that it does not change the threshold". The algorithm uses a classifier that will return a "1" when the signal is at least the "x" amount of standard deviations away from the mean (where x depends on the use case and the peaks that need to be detected). The influence mentioned by Jean-Paul's original algorithm should be used with care, because the system needs to detect longer lasting peaks and not only short ones. The pseudocode for this algorithm is as follows:

```
# Let y be a vector of timeseries data of at least length lag+2
# Let mean() be a function that calculates the mean
# Let std() be a function that calculates the standard deviaton
# Let absolute() be the absolute value function

# Settings (the ones below are examples: choose what is best for your data)
set lag to 5;        # lag 5 for the smoothing functions
set threshold to 3.5;  # 3.5 standard deviations for signal
set influence to 0;  # between 0 and 1, where 1 is normal influence, 0.5 is half

# Initialise variables
set signals to vector 0,...,0 of length of y;   # Initialise signal results
set filteredY to y(1),...,y(lag)              # Initialise filtered series
set avgFilter to null;                        # Initialise average filter
set stdFilter to null;                        # Initialise std. filter
set avgFilter(lag) to mean(y(1),...,y(lag));   # Initialise first value
set stdFilter(lag) to std(y(1),...,y(lag));    # Initialise first value

for i=lag+1,...,t do
 if absolute(y(i) - avgFilter(i-1)) > threshold*stdFilter(i-1) then
  if y(i) > avgFilter(i-1) then
   set signals(i) to +1;                   # Positive signal
  else
   set signals(i) to -1;                   # Negative signal
  end
  # Make influence lower
  set filteredY(i) to influence*y(i) + (1-influence)*filteredY(i-1);
 else
  set signals(i) to 0;                     # No signal
  set filteredY(i) to y(i);
 end
 # Adjust the filters
 set avgFilter(i) to mean(filteredY(i-lag),...,filteredY(i));
 set stdFilter(i) to std(filteredY(i-lag),...,filteredY(i));
end
```

As can be seen in this piece of pseudocode, there are two variables which can be changed to detect different kinds of peaks, namely the threshold and the influence. While there is also a lag setting, this will only delay the start of the peak detection (for smoothing purposes). The threshold sets the numbers of deviations the new measured value needs to be removed from the running average to be considered a peak. When this is set to 3.5, like in the pseudocode, a new value will be a peak when it is at least 3.5 times the stand deviation away from the average. The height of the influence takes the previous peak into account. When the influence is 1 the previous peak will be used in the calculation, while a influence of 0 does not take any previous peaks into account.

Data flow

The system was developed as an Android application, considering the different materials, algorithms and requirements. The application consists of different data streams from and towards it, like receiving user input and updating the Philips Hue lighting bulbs. The full overview of these streams of data is displayed in Figure 8, which is used during the second experiment.

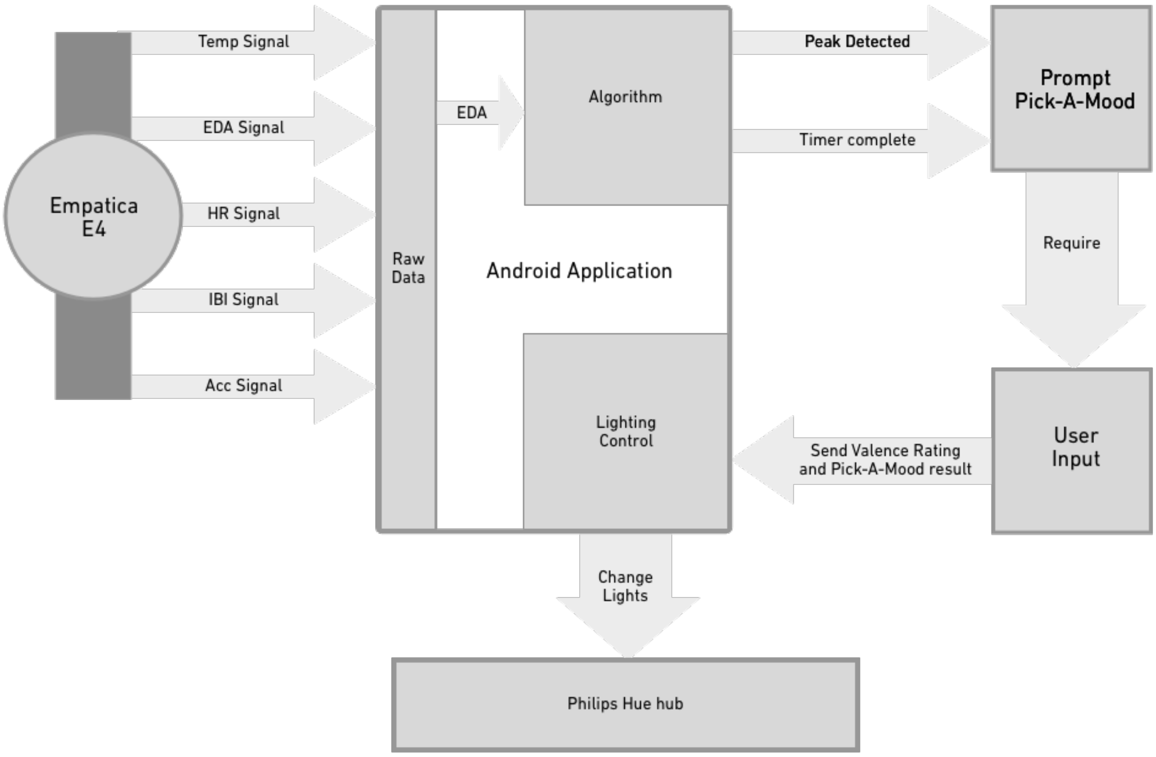


Figure 8 - Data flow of the android application

As shown in the data flow overview from Figure 8, the application requires the raw data input from the Empatica E4, which can be seen on the left side of the overview, which is send to the application by the Empatica E4 that is displayed on the far left.

This raw physiological data is used by the algorithm in the Android application. The algorithm module inside the application was an implemented version of either the smoothed z-score or the EDA explorer algorithm, which was discussed in Chapter 2.3.2. The algorithm can prompt the Pick-A-Mood interface in two ways, namely after detecting a peak and after a specified period of time. After detecting a peak, Pick-A-Mood is used to ask for the user input, which is needed to specify if the peak has a positive or negative valence. The period of time function can be used to generate an overview of the affective state of the user over a period.

When for example the user is required to at least pick one Pick-A-Mood character per 30 minutes, the system will have an overview of changes in the affective state of the user. The timer can also be disabled, making the Pick-A-Mood interface only respond to peaks detected by the algorithm.

The lighting control part inside the Android application uses the input the user gives in the Pick-A-Mood interface. This module checks the valence of the Pick-A-Mood character selected by the user and will act accordingly. This means that when the valence is negative, the lighting control will use the ambient lighting to improve the affective state of the user. Vice versa the same happens, when the user is in a positive mood, the system will change the lighting back to the neutral setting. When the lighting is already in the required setting, the lighting control will do nothing.

While the application is running, it will also report the data of each individual part. Meaning that it will log the physiological data received from the E4, the timing of the Pick-A-Mood interface, the Pick-A-Mood chosen characters and the status of the lighting system. The system gives an overview of these results (physiological data and Pick-A-Mood data) after the application is closed.

During the first experiment, only a part of the system is used. The goal of the first experiment does not yet require the system to detect peaks in the physiological data. Therefore, the algorithm used by the system will only rely on the timer which triggers the Pick-A-Mood interface after a period of time. The rest of the system however will be used to get the user input using Pick-A-Mood and to change the ambient lighting within the living room accordingly. From the stream of physiological data the system receives, it will log the EDA signal to compare the by the participant selected Pick-A-Mood characters with the EDA signal. The Philips Hue Bridge will respond to a timer, which activates when the mood induction video has ended, changing the ambient lighting to the preferred setting (either cosy, activating or neutral). The visual overview of which parts of the system are used can be found in Figure 9.

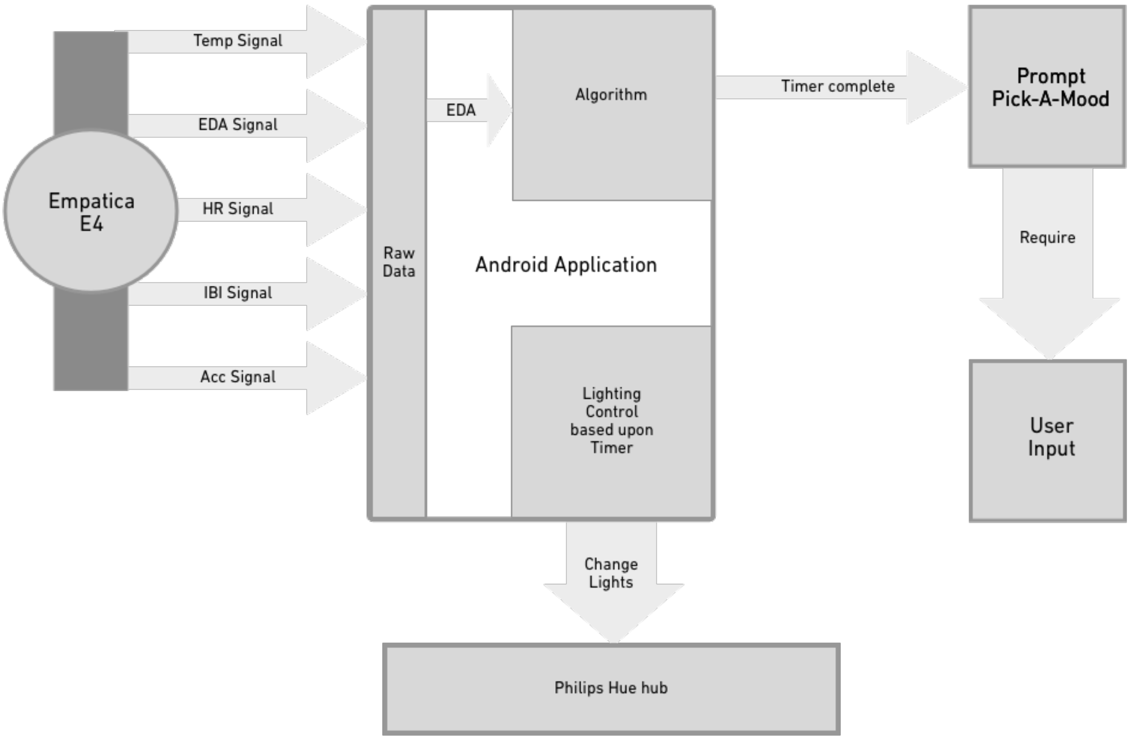


Figure 9 - System data flow overview for experiment 1

Design

The system consists of three separate interfaces which can be shown to the user. The GUI was the visual side of the application, with which the user interacted. The screen mostly shown was called the idle screen. This screen represented the state in which the system did not require input by the user. It shows the status of the connection with the Empatica E4 and can be seen in Figure 10.

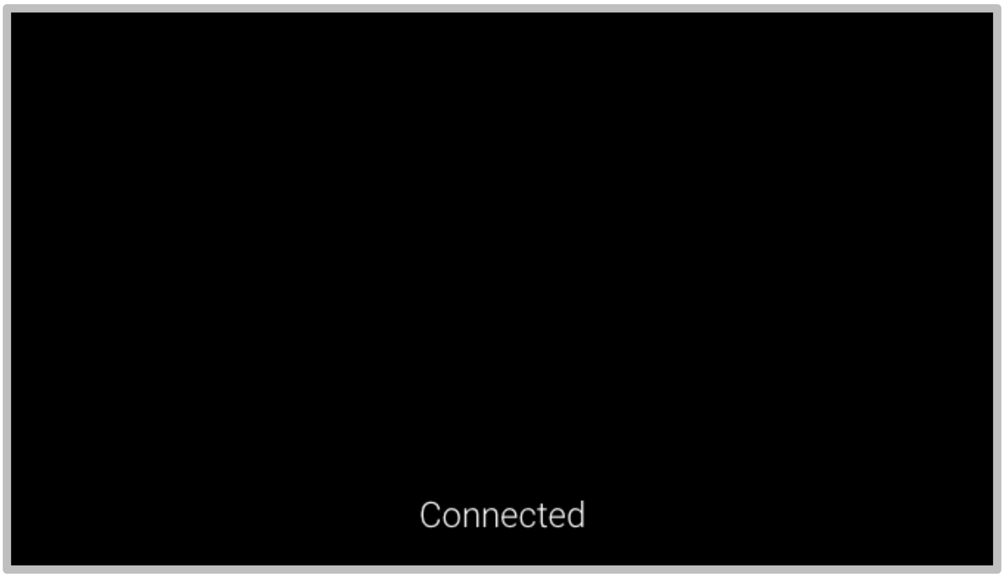


Figure 10 - Screen 1, the idle situation

In total, two screens required the input of the user, namely the Pick-A-Mood interface and the error screen. The Pick-A-Mood interface displayed the eight Pick-A-Mood characters with the request to choose the character that represented the affective state of the user best. The user was required to choose one character which the system used to establish the user's current affective state. The screen with the characters is displayed in Figure 11.

Figure 11 - Screen 2, the Pick-A-Mood Interface

The second interactive screen is the error screen. The error screen is only used when something goes wrong in the experiment and the system requires the help of the user to fix it.

This screen is mostly used to notify the user that the Empatica E4 is disconnected because it went out of the Bluetooth range. The error screen be seen in Figure 12.

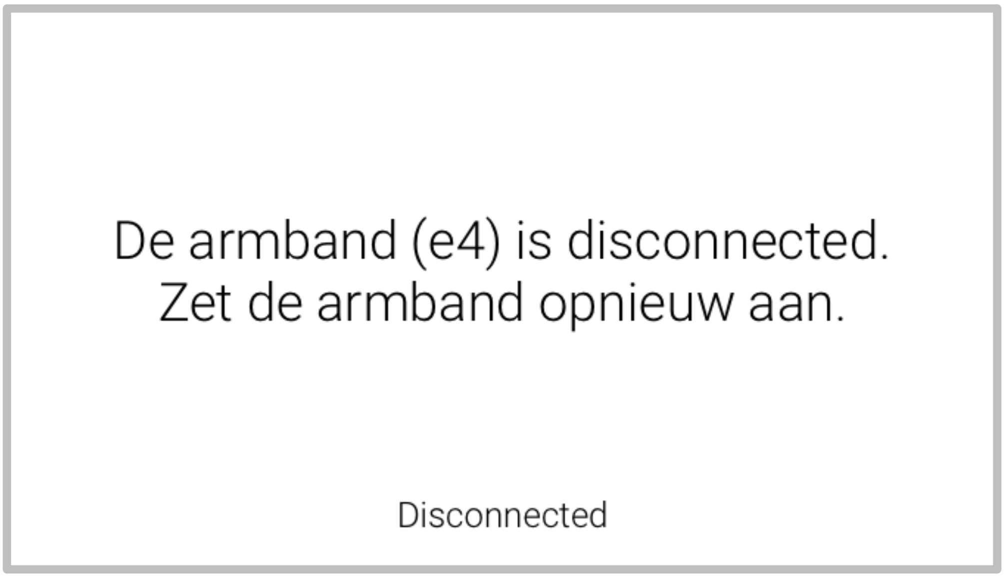


Figure 12 - Screen 3, the error screen

3.3.8. Living room

The living room which will be used during the first experiment is a meeting room within the DesignLab at the University of Twente. The room was modified to look like a living room. The living room consisted of three Philips Hue lightbulbs and two normal lamps, which are discussed in Chapter 3.3.3. See Figure 13 for pictures and the map of the room.

Figure 13 - Living room test setting (pictures + map)

The Phillips Hue light bulbs are divided over the room as can be seen in the map in the bottom of Figure 13. The participant will be seated on the couch in front of the television, meaning that he or she will directly see the three lighting sources on the left side of the room, while the two other light sources are behind him or her. The television itself will be used to display the mood induction videos and is a 46-inch flat screen monitor, this will be further discussed in chapter 3.4, the procedure.

3.3.9. Participant's own living room

For the second experiment, the living room of the participant herself is used. Figure 14 shows a map of the living room, including the position of the different lighting sources including the Philips Hue Light bulbs. The participant drawn in this map is the location on which the participant normally spends her evening, sitting in a chair watching the television or using her tablet.

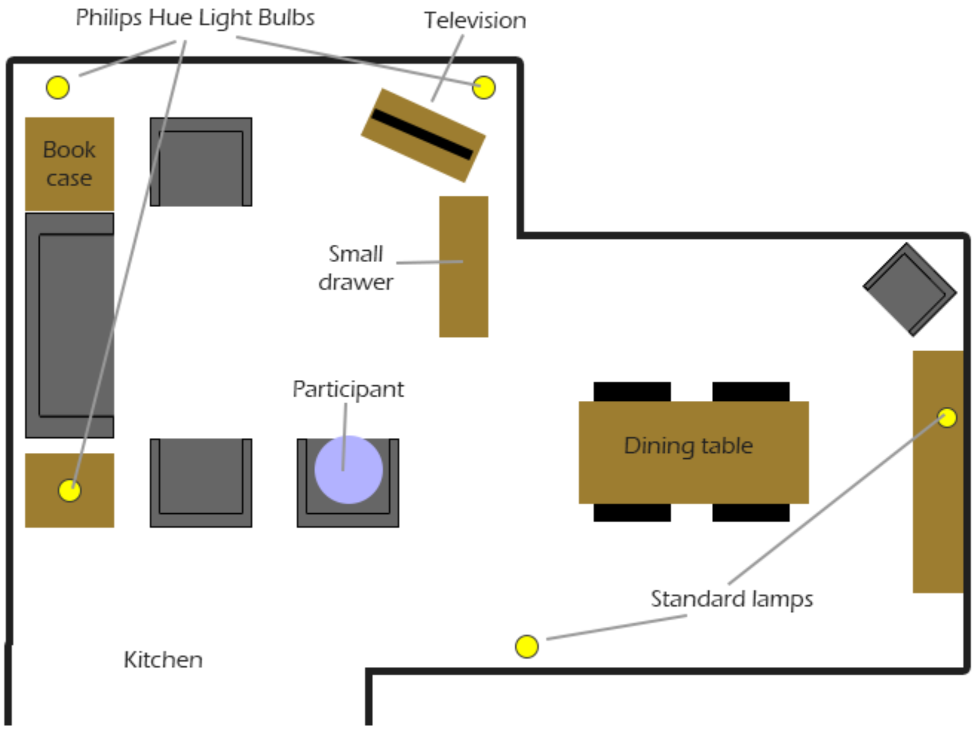


Figure 14 - Map of the participant's living room during experiment 2

3.4. Procedure

The experiments executed in this research are conducted through different procedures and which will be discussed in this section.

3.4.1. Experiment 1

The first experiment consists of two parts, namely the measuring of the physiological EDA signal and the self-reported mood measurement using Pick-A-Mood. This section describes the procedure of the experiment and will give an overview of the duration of each part of the user test. A schematic overview of the experiment procedure is displayed in Table 6.

The table shows a short waiting period after the mood inducing video. During this waiting period, the participant must wait two minutes between each Pick-A-Mood self-reported measurement. This waiting period of two minutes is based on research by Kuijsters et al. (2015) in which the participants are also required to wait two minutes between measurements. During these two minutes, the participant is not influenced by anything that happens outside the living room. The participant is also asked to not use their phone during this time. The participant is required to stay on the couch in the middle of the room during the waiting time. This waiting time is added to look at the influence of the ambient lighting over a period and not only shortly after the video.

Step	Description	Duration in minutes
1	The researcher explains the procedure of the experiment to the participant and lets the user sign the consent form.	2 minutes
2	The participant fills in the TAS-20 test to be tested for Alexithymia.	2 minutes
3	The researcher places the participant in the living room setup with the neutral ambience activate and starts the E4 EDA recording.	20 seconds
4	The TV starts playing the video and the participant starts watching the mood induction video clip.	2 minutes
5	The researcher records initial Pick-A-Mood and set the ambience to either activating or cosy or keep it neutral.	
6	Waiting period for the participant.	2 minutes
7	The participant need to choose a Pick-A-Mood character that is displayed on the Nexus 6 screen.	
8	Waiting period for the participant.	2 minutes
9	The participant need to choose a Pick-A-Mood character that is displayed on the Nexus 6 screen.	
10	Waiting period for the participant.	2 minutes
11	The participant need to choose a Pick-A-Mood character that is displayed on the Nexus 6 screen.	
12	Waiting period for the participant.	2 minutes
13	The participant need to choose a Pick-A-Mood character that is displayed on the Nexus 6 screen.	
14	Waiting period for the participant.	2 minutes
15	The participant need to choose a Pick-A-Mood character that is displayed on the Nexus 6 screen.	
16	The participant is asked to fill in a questionnaire about the atmosphere in the room.	1 minute
17	Room for questions for the participant.	(5 minutes)
Total time per participant		25 minutes

Table 6 - Schematic overview of the test procedure

3.4.2. Experiment 2

This section first describes the procedure of the second experiment, thereafter it shows the schematic overview of the experiment. In addition, a visual overview of the second experiment is displayed.

The second experiment consists of two parts. The first part of this experiment will focus on calculating and setting the baseline for one participant and selecting parameters for the peak detection algorithm using the baseline. In the first part of the second experiment, the characteristics of the participant's physiological data is referred to as the baseline. The baseline consists of all the possible values in the physiological data of the user, like the participants average EDA value or the maximum value or height of the heartrate. With the baseline, it is possible to compare real-time measured peaks to a big set of pre-recorded (physiological) data, resulting in an emotional event detection system. For example, the participant can have a EDA signal which is on average quite high, but this does not mean that there is an emotional change happening, while at another participant it would indicate that an emotional change is happening because his EDA value is never this high.

The second part focusses on improving the mood of the participant by changing the ambient lighting. With the results from the first part of the experiment it is possible to adapt the peak detection algorithm parameters and tailor the system to detect affect-related peaks in the physiological data of the participant (real-time).

The goal for both the first part of the experiment as the second part of the experiment is on following and recording the participant in their own environment. This is also called evaluating the system in "the wild". By testing and evaluating the effectiveness of the system in the user's own environment, this experiment can rule out the influence of the research environment influence and show the effect of ambient lighting in the user's own living room. The power of testing in the wild is discussed in several other articles, which show the power of this method (Rooksby, Rouncefield, & Sommerville, 2009; Kaikkonen, Kekäläinen, Cankar, Kallio, & Kankainen, 2005).

See Table 7 for the schematic overview of experiment 2. The days are numbered and relate to the day of the week, starting with Sunday being 0 and Saturday being 6. The visual overview of Table 4 is displayed in Figure 15. It shows the procedure of the second experiment, displayed per day and day part.

Day	Step (Description)	Duration (Minutes)
0	Explain the experiment, including the context mapping diary, the TAS-20 test and the E4 wristband. The participant needs to sign the informed consent form to be able to participate in the experiment.	30 m
	Filling in the TAS-20 test for Alexithymia.	10 m
	Background interview about the participant's general information (demographics and living situation).	10 m
1	The participant wears the Empatica E4 and will write down in her diary all events that cause a change in the participant's affective state.	Whole day
2	The participant will get interviewed by the researcher at the start of the day (around 8:30 in the morning) about the events that the participant wrote down in the context mapping diary of the previous day. Thereby the data stored on the E4 will be downloaded and the E4's memory will be cleared.	30 m
	The participant wears the Empatica E4 and will write down in her diary all events that cause a change in the participant's affective state.	Whole day
	The ambient lighting (including the system) will be installed at the participant's living room and the atmosphere perception will be tested around 22:00.	1 – 1.5 h
3	The participant will get interviewed by the researcher at the start of the day (around 8:30 in the morning) about the events that the participant wrote down in the context mapping diary of the previous day. Thereby the data stored on the E4 will be downloaded and the E4's memory will be cleared.	30 m
	The participant wears the Empatica E4 and will write down in her diary all events that cause a change in the participant's affective state.	Whole day
	The parameters of the algorithm are tailored to the previously recorded physiological baseline and context mapping results. This will be done at the beginning of the afternoon with 2.5 days of data.	/

	In the evening, the ambient lighting is activated with the system. The E4 will stream the data to the system and the ambient lighting will adapt to this data.	1.5 h
4	The participant will get interviewed by the researcher at the start of the day (around 8:30 in the morning) about the events that the participant wrote down in the context mapping diary and the ambient lighting of the evening of the previous day. Thereby the data stored on the E4 will be downloaded and the E4's memory will be cleared.	30 m
	The participant wears the Empatica E4 and will write down in her diary all events that cause a change in the participant's affective state.	Whole day
	In the evening, the ambient lighting is activated with the system. The E4 will stream the data to the system and the ambient lighting will adapt to this data.	1.5 h
5	The participant will get interviewed by the researcher at the start of the day (around 8:30 in the morning) about the events that the participant wrote down in the context mapping diary and the ambient lighting of the evening of the previous day. Thereby the data stored on the E4 will be downloaded and the E4's memory will be cleared.	30 m
	The participant wears the Empatica E4 and will write down in her diary all events that cause a change in the participant's affective state.	Whole day
	In the evening, the ambient lighting is activated with the system. The E4 will stream the data to the system and the ambient lighting will adapt to this data.	1.5 h
6	The participant will be interview by the researcher about her experiences during the week (including the ambient lighting and the diary of day 5). This interview will contain questions about both parts of the experiment.	1.5 h

Table 7 - Schematic overview of the procedure of the second experiment

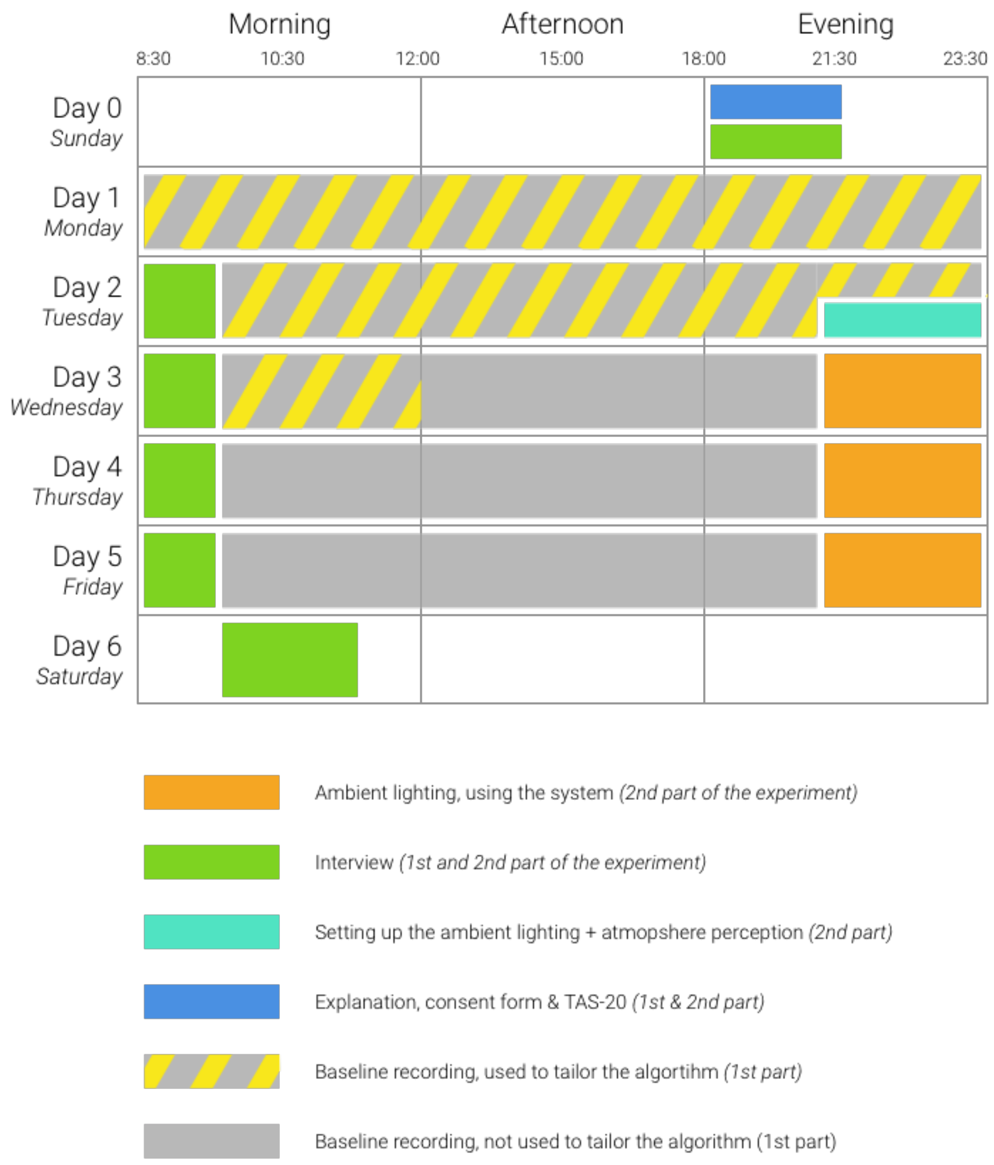


Figure 15 - Visual overview of the procedure of the second experiment

3.5. Data analysis

With the procedure for both experiments from the previous chapter, the resulting data will be analysed. The data analysis is done per experiment; therefore, this section is divided into experiment 1 and 2. The different parts of the data analysis are discussed in the order in which they occur in the procedure per experiment (which is the chronological order).

3.5.1. Experiment 1

In the first experiment three lighting settings are used, namely the cosy, activating and neutral setting. The neutral state is chosen to compare the influence of the other two lighting settings to. The neutral setting does not change the lighting during the experiment, while with the activating and cosy setting the ambient lighting changes directly after the video has ended.

Influence of the video and the ambient lighting on the self-reported mood

To analyse the influence of the video and the ambient lighting on the self-reported mood of the participants in the first experiment, two analysis were executed. First, the Pick-A-Mood characters chosen by the participants were analysed by comparing the self-reported mood between the participant per 2 minutes. This comparison is done by looking at the valence of the picked characters and the number of picked characters that correspond with the sad mood. Second, the changes in the EDA signals were analysed by comparing the retrieved data during and after the video. This analysis was done in SPSS, a program used for statistical analysis.

Influence of the video and the ambient lighting on the physiological data

To investigate the influence of the video and the ambient lighting on the mood or affective state of the participants, several analyses were executed. First, the effect of the video was analysed. This is because the video might influence the physiological data in such a way that any changes or peaks in the data might be caused by the video. This information can be used in the second experiment for the arousal detection via peaks in the EDA signal. When sad events in the video cause the EDA signal to peak it might indicate that the signal responds to negative changes in the affective state of the participant. This is checked for two moment in the video, namely the point at which the scene switches from happy to sad (the start of the hospital scene) and after the video itself.

With the information gathered, the effects of the other two lighting settings can also be compared to each other and especially with the neutral lighting setting. This is done by looking at the difference between the neutral ambient lighting state and the two other states. The lighting might either distract the participant from the effects of the video, help the participant to return to a positive mood sooner or stimulate the EDA signal to increase even further. To do this, the data of the participants is sorted and combined into three data streams, for each lighting setting one. These averages are then used to calculate if there are any statistical differences between them.

Atmosphere perception

To investigate whether the room, used for the user test, has the right atmosphere to improve the mood, the perception of the atmosphere is tested. This is done by using a shorter version of the Vogels atmosphere questionnaire (Vogels I. , 2008), which was also used by Kuijsters et al. (2014). In total, there are 12 atmosphere items chosen which need to be scored on a seven-point Likert scale by the participants. The seven-point scale ranges from 1 being “not applicable at all” to 7 being “totally applicable”. Thus, the higher the number given by the participant, the higher the atmosphere item is applicable to the used ambient lighting setting. These scores can then be averaged into the four main atmosphere dimension. Table 8 shows the four dimensions in combination with the three items per dimension. An ambient lighting setting with a higher score on the cosiness and liveliness scale will, according to the existing research, positively improve the mood more in comparison to settings with a lower score.

Cosiness	**Liveliness**	**Tenseness**	**Detachment**
Cosy	Lively	Terrifying	Formal
Safe	Inspiring	Threatening	Chilly
Intimate	Stimulating	Tense	Business

Table 8 - The used atmosphere item words per dimension.

3.5.2. Experiment 2

Experiment 2 consists of two parts, of which the second part builds on the results of the first part. In the first part, the physiological data will be gathered using the Empatica E4. The wristband will record and store the physiological data of the participant for each of the five days for the full duration of the day. This will come down to at least 12 hours of physiological data of the participant each day, which can be used to create the physiological baseline of this participant. With two and a half days of physiological data (Monday till Wednesday morning), the baseline of the participant is defined. The measured data gives an impression on the changes, peaks and maxima that happen per physiological signal, but the algorithm will only use the EDA signal. This information is used in the second part of the experiment, namely to tailor the peak detection algorithm to the physiological data (baseline) of the participant.

Context mapping

To get insight into the emotional events that occur to the participant during the day, the context mapping diary is used. As discussed before, the creation of a baseline in physiological data is needed to be able to differentiate between natural peaks and others peaks in the participant's data, see Figure 7. By combining the baseline with the context mapping method, it is possible to compare the self-reported (context mapped) affective changes with the changes in the physiological data.

In the second experiment, the context will provide an overview of the events that happened during a day of measuring. By using the diary type of context mapping, not every event that has an influence on the affective state will be detected, but it should pick up most of the bigger influences on the affective state of the participant. Thereby, it will not give a perfect timeline overview of the mood of the participant per time of the day. However, the diary gives a subjective view of the context. By letting the participant fill in the diary, only things that are worth of being written down according to the participant will be reported. The goal of the context mapping in this research is to get insight in what a person experiences during a regular day and how the E4 data might represent events that occur during this day.

Tailoring the peak detection algorithm

With the results from the first part of the experiment it is possible to tailor the peak detection algorithm to the physiological baseline of the participant. To do this, first the baseline and the context mapping results are combined. This will be done by taking the physiological data and placing the context mapped events on top of this data. The context mapped events all have their own physiological data, which will be used to define how a mood changing event looks in the physiological data of the participant. By combing events from the context mapping and the baseline, an event that has influence on the affective state of the participant will be defined in terms of physiological characteristics. This will be done by looking at the peaks and changes in physiological data correlated to the events and comparing them with the baseline to see if the events differentiate from the baseline in any way. This way the context mapping results are used as the ground truth.

The algorithm can detect different kind of peaks depending on which parameters are used. With the information about the baseline and the context mapping different parameters are tested to come up with the optimal parameters which detect most of the context mapped events. This will be done for both the Smoothed Z-score algorithm and the EDA explorer. The Smoothed Z-score algorithm has three parameters which will be used, namely the influence, threshold and minimum value of the peak. The EDA explorer has more parameters, namely a minimum amplitude, an offset, a filter frequency, a filter order, a max rise time and a max decay time. Both algorithms will be scored on accuracy and precision, which will result in using the best algorithm for this participant.

Atmosphere perception

At the start of the second part of the experiment (at Tuesday evening), the perception of the atmosphere is tested before the atmosphere is used in the experiment. The Philips Hue API uses the values of Brightness, Hue, Saturation and Colour Temperature to create a specific colour with the light bulbs, like in the first user test. Four atmospheres are tested together with the participant to investigate how the participant perceives these different ambient lighting settings. Two atmospheres are the neutral and cosy setting from the first experiment, which are reproduced (in a slightly adapted version) in the living room of the participant. The researcher will then use the perception results of these four atmospheres to decide whether more different atmospheres need to be tested. This could be the case if for example all atmospheres score low on the Vogel's atmosphere perception scale for cosiness and liveliness. The neutral ambient lighting setting is selected by comparing the different lighting settings to the normal lighting the participant has within her room, while the cosy setting is selected by taking the average score of the different setting for cosiness and liveliness. The setting with the highest average score will be used as the cosy ambient lighting setting by the system.

Adaptive lighting influence

With the tailored peak detection algorithm, the system changes the ambient lighting when needed. The influence of the changes in ambient lighting is analysed in two ways. First, it is tested by combing the Pick-A-Mood results, the Empatica E4 streamed signal and the detected events or peaks during the evening. The second way uses the conducted interview results to investigate the experience of the participant about the lighting and the usage of the lighting. This can be used because the lighting influences the mood and feelings of the participant, which can be reported in the interview. This second way gives an opinion of the effect of the system, while the first way gives a data based effect of the system.

The first way of analysing the data uses the results of the Pick-A-Mood in combination with the ambient lighting states during the evening to look at the effects of the ambient lighting. This will be done with three times one and a half hours of data, namely for the Wednesday, Thursday and Friday evenings between 22:00 and 23:30.

Interviews

During the experiment the participant will get interviewed at different times (the green blocks in Figure 15). This is done because there is only one participant for the second user test, which results in the need to acquire all the information possible about the participant and how the participant experienced the user test. To get the most information from the single participant the interviews are based upon a data gathering method which is called qualitative research. Qualitative research is the methodology which aims gathering an in-depth understanding of how a participant behaves and responds, but also why the participant does this (Alasuutari, 2010). With the use of qualitative research a basis can be created to conduct a quantitative study on, which will focus on seeking empirical support for the results.

The interviews used for this user test are semi-structured, following a list of questions and topics per day while being able to stray away from the questions when the interviewer feels that this is appropriate (Cohen & Crabtree, 2006). The choice for using a semi-structured interview setup is because each interview will only take place once, meaning that the participant needs to be able to talk about themselves. According to Carlson et al. the participant must believe in the sincerity of the interviewer's learning role, which can only be achieved when the interviewer that the interviewer attributes significance to the participant's beliefs, behaviours, and patterns of perception (Carlson, Siegal, & Falck, 1995). By using the semi-structured qualitative interview method, several interviews are prepared which each focus on a different part of the user test.

In the research by Patton (1990) they identify three types of qualitative interviewing for research or evaluation, namely informal conversation interview, the interview guide approach and the standardized open-ended interview. These three types are all open-ended interviews and are based upon the semi-structured method discussed before. The interview guide approach is used for the second experiment, in which the interviewer has a list of topics (or questions) which need to be covered. The interviewer is free to vary the wording and order of questions in this type of qualitative research. The interviews are audio recorded which is done to not miss or forget any information afterwards. For the experiment, we distinguish the following interviews:

- **Questions before the start of the user test.** Before the user test starts the participant will be interview to create a profile. The questions will be used to introduce the method of interviewing to the participant, but also gather the needed information about the background of the participant.

- **Question per marked event in the diary.** The participant will write down each event in the context mapping diary, but the level of detail might depend on the mood of the person or the importance of the event. With a small number of questions per event we will try to get a good idea about what happened at that specific event and the effects of this event on the person.
- **Questions per day.** At the start of each day the participant will need to reflect on the previous day. At the first part of the user test this is done to give extra context to the data of the day before, while in the second part it is mostly focussed on the experience of the participant with the system.
- **Summarizing questions about the baseline.** After the baseline measuring is complete, the participant will need to answer questions about the previous days and how he or she has experienced it. This is done because the participant might have had the best two days of his or her life, in which case the data cannot represent a regular day.

The value of qualitative research and interviewing comes from the flexibility and openness the researcher has according to Sewell (1998). In the research by Kvale (1996), they discuss five methods to analyse the qualitative interview results, namely meaning condensation, meaning categorization, narrative structuring, meaning interpretation and ad hoc methods. In the results and conclusion of this experiment, the methods meaning condensation and meaning interpretation will be used. Meaning condensation is the condensation of the meanings expressed by the interviewee into shorter formulations done by the interviewer. The main sense of what is said should be rephrased into a few words with this method. Meaning interpretation is used to more or less speculate the meaning or interpretations of the question answers. This can be used to re-contextualize the statements made by the interviewee into a broad frame of reference according to Kvale. By combing these two methods the researcher can use parts of the interview answers and condensate longer answers into briefer statements. Thereby, the researcher can write down interpretations of the answers. It should be noted that this last method can lead to speculative interpretations of the answers.

4. Results for Experiment 1

The experiment is conducted with a total of 20 participants on the 11th and 12th of May in 2017. In total the Empatica E4 disconnected once per participant, in which case the error screen was used to tell the participant to turn the wristband back on.

4.1. Pick-A-Mood

The Pick-A-Mood results of all 20 participants, per setting, are displayed in Table 9. This table shows the character each participant has picked at a specific moment during the experiment. As can be seen in the table, after the mood induction video, the Pick-A-Mood results show a clear sad mood at almost all participants. 16 Out of the 20 participants have a negative self-reported mood directly after the video, of which only one has not picked the "Sad" Pick-A-Mood character (namely the bored character). Two minutes after the video, only 9 out of the 20 participants still have a negative self-reported mood, of which only five picked the "Sad" Pick-A-Mood character.

The Pick-A-Mood results per lighting setting show about the same behaviour as the overall results, see Table 10. After the video 4 out of the 6 participants that had an activating setting reported a negative mood, for the cosy setting this is 6 out of the 7 participants and for the neutral setting it is 5 out of the 6 participants. After two minutes of waiting, the activating and cosy setting decrease the amount of negative reported moods by half (2/6 for activating and 3/7 for cosy), while the participants that negatively self-reported their mood after two minutes is only reduced by 1. After four minutes however, this difference between the neutral and other lighting settings has already disappeared, because of the participants that experienced the neutral lighting setting only one reported a negative mood (and 0 reported a sad mood).

Lighting Setting	**Pick-A-Mood**						
	Before video	*After video*	*2 min*	*4 min*	*6 min*	*8 min*	*10 min*
Activating	Cheerful	Sad	Sad	Calm	Calm	Calm	Calm
Activating	Cheerful	Sad	Sad	Calm	Calm	Calm	Calm
Activating	Calm	Sad	Calm	Calm	Calm	Calm	Calm
Activating	Relaxed	Relaxed	Calm	Tense	Relaxed	Relaxed	Tense
Activating	Relaxed	Calm	Cheerful	Relaxed	Relaxed	Irritated	Calm
Activating	Relaxed	Sad	Relaxed	Bored	Tense	Bored	Bored
Cosy	Cheerful	Sad	Sad	Calm	Calm	Calm	Calm
Cosy	Calm	Sad	Calm	Cheerful	Relaxed	Bored	
Cosy	Relaxed	Relaxed	Calm	Tense	Relaxed	Relaxed	Tense

Cosy	Calm	Bored	Bored	Bored	Bored		
Cosy	Calm	Sad	Relaxed	Sad	Sad	Bored	Bored
Cosy	Cheerful	Sad	Bored	Tense	Relaxed	Relaxed	Calm
Cosy	Tense	Sad	Calm	Calm	Tense	Calm	Bored
Neutral	Tense	Sad	Sad	Calm	Calm	Calm	Calm
Neutral	Calm	Sad	Calm	Calm	Calm	Calm	Calm
Neutral	Relaxed	Relaxed	Relaxed	Relaxed	Relaxed	Relaxed	
Neutral	Tense	Sad	Tense	Calm	Calm	Sad	Calm
Neutral	Relaxed	Sad	Tense	Relaxed	Calm	Relaxed	Relax
Neutral	Bored	Sad	Sad	Bored	Bored	Calm	Calm

Table 9 - Pick-A-Mood results from experiment 1 (each row being a different participant)

	After the video	2 minutes	4 minutes
Activating - N*egative*	4/6	2/6	2/6
Cosy - *Negative*	6/7	3/7	4/7
Neutral - *Negative*	5/6	4/6	1/7
Activating - *Sad*	4/6	2/6	0/6
Cosy – *Sad*	5/7	1/6	1/6
Neutral - *Sad*	5/6	2/6	0/6

Table 10 - Negative self-reported moods per lighting setting including the amount of “Sad” reported moods per lighting setting for the first 4 minutes after the video.

The effect of the ambient lighting on the affective state of the participant, does not show the same results as in the existing research. Where Kuijsters et al. (2015) report a clear improvement of the mood by exposing an elder person to ambiences with a clear positive affective meaning, this experiment does not show this improvement. The mood in the activating and cosy atmosphere is only shortly negative after the video (80% self-reported a negative mood), but two minutes after the ending of the video, it has already gone back to a more positive mood (only 45% self-reported a negative mood). When comparing the self-reported mood per lighting setting in Table 10, it shows that the amount of negative self-reported moods decreases more slowly at the participants that experienced the neutral lighting setting. This only holds for the first two minutes after the video, at which four out of the six participants self-report a negative mood (which is a decrease of 1). At the other two lighting settings, the amount of self-reported negative moods is decreased by 50% and is respectively 2 out of 6 and 3 out of 7.

4.2. Physiological data (E4)

In this experiment, the mood in recorded using the Pick-A-Mood self-reported method, but also the physiological EDA data is recorded during the experiment. The EDA signal is processed per individual participant and differed a lot between the participants, ranging from an average EDA signal of 0.05 to an average of more than 1. This difference has two reasons: First, each participant has his or her own skin conductance (meaning that some people have more active sweat glands in the skin than others), thereby each participant placed the wristband on his or her own wrist, which can create a difference in how close the E4 was placed to the skin, which can influence the signal.

The physiological data of the participant's is analysed in three steps, first the effect of the video on the EDA signal is investigated. Second, the effect of the video per lighting setting is investigated. Third, the three lighting settings are compared to each other. The effect of the video is investigated because at the ending of the video the lighting also changed, meaning that both events could have influenced the EDA signal.

Starting with the effect of the video on the EDA signal, the mean EDA signal of all participants is divided into two groups, namely during and after the video. During the video indicates the measurements of the first 3 minutes and 36 seconds, during which the video was playing. The other group, after the video, has the same duration of data, but contains the EDA signal of the participants after the video has ended (so 3:36 – 7:12). Of these two groups, the means were taken and visualised in a boxplot, showing the difference between them. This visualisation can be found in Figure 16. The boxplots in this figure show almost the same ranges and mean for both during and after the video.

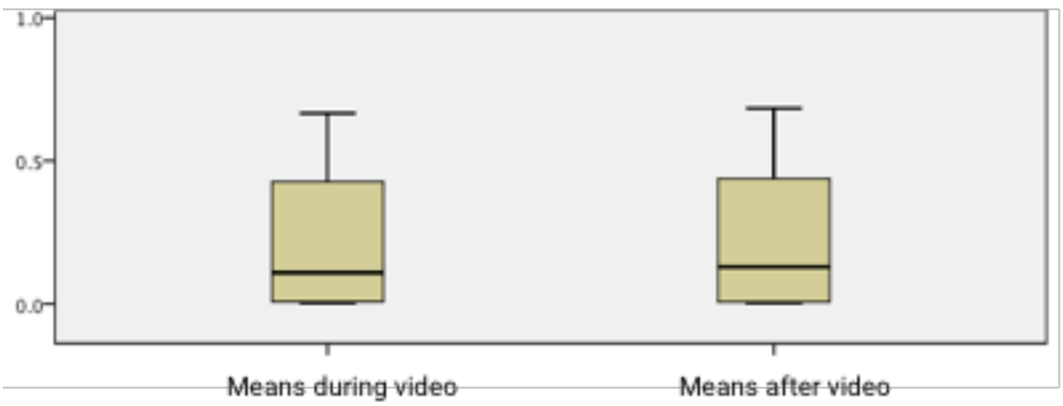


Figure 16 - Boxplot of the means of the EDA signal during and after the video (for all 20 participants)

Next, the effects of the video are investigated per lighting setting. This is done as before with the boxplots, but this time a boxplot is created per six participants that experienced the same lighting setting. These boxplots can be found in Figure 17. In addition to the data visualisation, the data is also described in terms of minimum, maximum, mean and standard deviation in Table 11.

For the activating lighting setting, there is a difference between the minimum and maximum of the EDA means, but there is almost no difference between the middle two quartiles. The range of the activating means during the video are limited to 1,79 (0.01 - 1.80), while after the video the range increases to 2.21 (0.00 – 2.21). This difference can also be seen in the size of the standard deviation and the height of the mean, which both increase after the video. For the cosy lighting setting, the same difference is seen. The range increase from 0.50 (0.00-0.50) to 0.66 (0.02 – 0.68). The mean and the standard deviation also increase after the video, but this is a smaller increase in comparison to the activating setting. For the neutral lighting settings, the EDA data does not change a lot. The range increases only a little, by 0.02 (0.45 to 0.47). The mean stays almost the same in both groups and even the standard deviation only changes by 0.01.

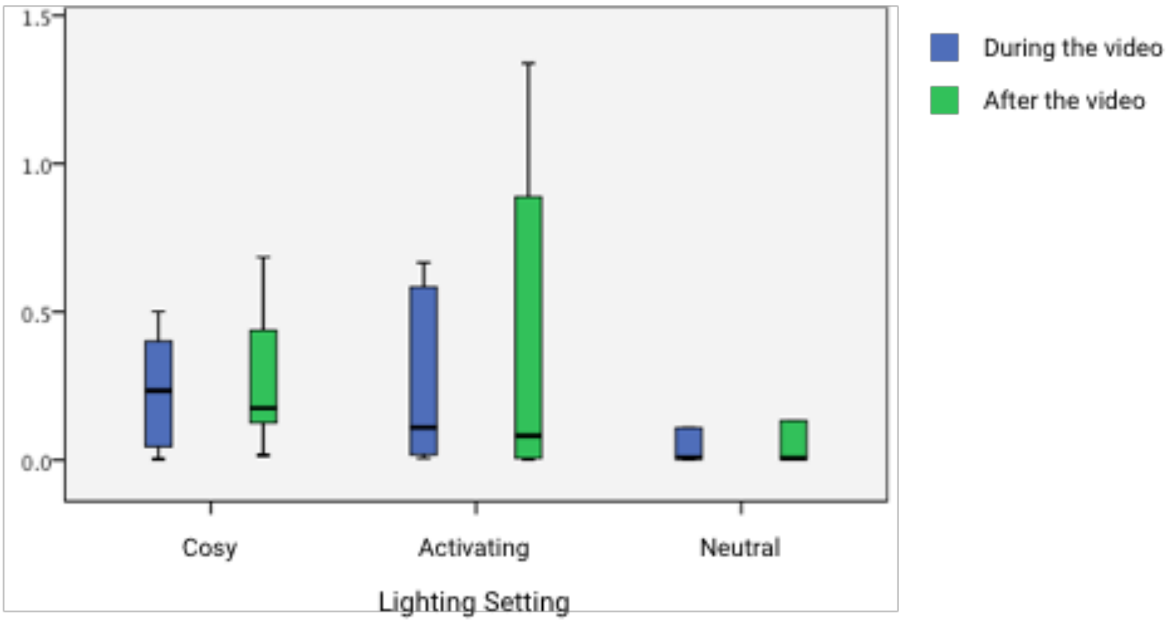


Figure 17 - Boxplots of the mean EDA signal per ambient lighting setting

Lighting Setting	Group	N	Minimum	Maximum	Mean	Std. Deviation
Activating	Mean during video	8	.01	1.80	.40	.62
	Mean after video	8	.00	2.21	.52	.82
Cosy	Mean during video	6	.00	.50	.24	.19
	Mean after video	6	.02	.68	.27	.25
Neutral	Mean during video	6	.00	.45	.09	.18
	Mean after video	6	.00	.47	.10	.19

Table 11 - Descriptive overview of the mean EDA signal per lighting setting

Comparing the three discussed lighting settings, a difference can be noticed between the neutral setting and the other two settings. While the EDA data at neutral setting does not seem to be influenced by the video, there is a big difference between the EDA signal of the other two lighting settings before and after the video. The physiological EDA data results show the effect of the ambient lighting on the EDA signal. While the signal does not show any video related changes in the neutral setting, it does show big difference between the EDA signal during and after the video for the other two lighting settings. This change in the EDA signal shows how the EDA signal is directly influenced by things happening in the environment of the participant. This might indicate that the EDA signal can be used to detect changes in the ambient lighting around the participant.

4.3. Atmosphere perception

With the atmosphere questionnaire results from each participant, an overview is created containing the average rating per atmosphere item, see Table 12. Each lighting setting uses the input from the group of participants that have experience that specific lighting setting after the video had ended.

	Activating	Cosy	Neutral
Cosy	5	6	5
Safe	6	6.1	5
Intimate	5	5	4
Lively	5	5.1	3
Inspiring	4	4.6	4
Stimulating	4	4.3	4

Terrifying	1	1	1
Threatening	1	1	1
Tense	2	1.9	2
Formal	4	2	3
Chilly	3	3	3

Table 12 - Average atmosphere items rating per lighting setting

The individual ratings per atmosphere item does not say enough about how the participant experienced the ambient lighting, therefore the dimension previously discussed in Table 8 are used. This results in an average rating (between 1 and 7) per atmosphere dimension per lighting setting. This second, smaller overview can be found in Table 13. Both tables show an improvement in the cosiness and liveliness of both ambient lighting settings in comparison to the neutral setting. While the neutral setting scores around the 4.5 on cosiness and 3.5 on liveliness, the activating lighting setting scores a 5.15 on cosiness (0.65 higher) and a 4.3 on liveliness (0.8 higher). The cosy setting has even higher ratings for the applicability of the cosiness and liveliness dimensions, namely a 5.7 for cosiness and a 4.7 for liveliness, which is 0.65 higher than cosiness and 0.4 higher for liveliness in comparison to the activating ambient lighting setting.

	Activating	Cosy	Neutral
Cosiness	5,167	5,714	4,556
Liveliness	4,278	4,667	3,556
Tenseness	1,389	1,286	1,389
Detachment	3,778	2,381	3,056

Table 13 - Atmosphere rating per dimension on a scale from 1 (not applicable at all) to 7 (Totally applicable)

As can be seen in Table 13, there are differences between the atmosphere perception of the activating and cosy setting compared to the neutral setting. The table shows that the neutral ambient lighting gives the participants the feeling of a normal living room, namely a positive, safe and cosy room, with a score of 4.5 for cosiness and 3.5 for liveliness. When the lighting inside this living room changes to a cosier setting it does improve the cosy rating, showing that the living room does become cosier. The cosy setting improves both the liveliness and cosiness by more than 1 point on the 7-point scale of applicability to a 5.7 for cosiness and a 4.7 for liveliness. The activating setting does also improve the perceived atmosphere, except for the cosy item rating. This setting gets a rating of 5.2 for cosiness and 4.3 for liveliness, placing it between the cosy and neutral setting for both the cosiness and liveliness atmosphere rating.

These results show that the positive atmosphere dimensions (cosiness and liveliness) increase when a cosier lighting atmosphere is used. The activating lighting setting also produces a more positive atmosphere, but lacks the improvement in cosiness, and scores on average lower in comparison to the cosy atmosphere. This shows that it is possible to recreate the atmospheres researched by Kuijsters et al. in different living room settings by using only three Philips Hue lightbulbs and two regular lighting sources.

5. Results for Experiment 2

The experiment was executed in week 25 (2017) with one female participant (n=1). This chapter will start with the results of the first part of the experiment, after which it continues to the results of the second part. This way, the results follow the same order as the procedure. This approach is chosen because the results of the first part are used to tailor the system, used in the second part of the experiment. Thereby, there were no errors during the usage of the system in the second experiment, meaning that the system only used the Pick-A-Mood and idle screen.

5.1. Context mapping

Per day the participant was asked to mark the events in which she felt an emotional change or simply an event that triggered a certain emotion. These events are marked in the context mapping diary for each day. In the appendix (10.3), each of the mapped events per day are discussed and described in chronological order. Note that only the first two and a half day is used to adapt the peak detection algorithm.

With the context mapping diary, the events that the participant reported as influencing her mood were noted in the diary. On average, 2.6 events per day are reported in the diary by the participant. Of these 13 total events, five were negative and only one event was self-reported as sad. These events give insight into the changes in physiological data of the participants while she experiences an emotional event. Most of the reported events have a positive influence on the affective state of the participant, however for the peak detection algorithm no distinction is made between a positive or negative event. Concluding, the context mapping results give insight into the emotional events that happened to the participant during the week of measuring. The mapped events show what kind of events influence the mood of the participant and how this influence related back to the affective states of Pick-A-Mood. However, the number of mapped events is not high, which might indicate that not all emotional events that occurred during the day were noticed by the participant.

5.2. Baseline

The baseline measurement consists of a data set of physiological data, that is multiple days long (5 in this experiment). These five days of physiological data are used to get an impression on the changes, peaks and maxima are for the participant. By knowing what these characteristics are, it can be possible to define what a normal physiological signal looks like and how a peak in this signal can be defined. The physiological data per signal per day is displayed in Figure 18. As can be seen in this figure, the physiological data is divided into EDA, BVP, Accelerometer, HR and Temperature. Note that only the first two and a half days are used to create the baseline for the second part of the experiment. The other days are still measured and reported to get a full week of information, which can be useful for future research.

EDA. The EDA signal shows an average in the data of an EDA between 0.2 and 0.4 (μS). Most of the time, the signal is between these two values, but when it goes higher than 0.5 it ultimately returns to the average value between the 0.2 and 0.4 μS. The EDA signal does also show a peak at the start of each day.

BVP. The blood volume pulse (BVP) signal does not show any clear characteristics or baseline behaviour. There average signal varies between -3.5 and -3.6 and sometimes sometime shows bigger differences in the signal for a short period of time, which might indicate that something happened to or with the participant. However, these differences do not match with peaks or changes in the other physiological signals.

Accelerometer. The accelerometer data shows the movement of the participant during the day. In algorithm like the EDA explorer this information is used to check if the changes in the EDA signal do not occur because of movement (of the wristband or participant). The physiological data of the participant shows however that the EDA data peaks occur both while the accelerometer value is low and when the accelerometer value is high.

HR. The heartrate (HR) physiological signal shows a correlation with the accelerometer data, which shows that it is influence by the movement of the participant. Thereby it also shows changes without any movement, which might indicate an event that occurred to or with the participant. The average HR of the participate is between 70 and 80 beats per minute (bpm), with peaks that can go towards the 120 bpm, which is normal for the age of the participant according to the American Heart Association (2016).

Temperature. The temperature of the participant ranges between 30 and 40 degrees Celsius. This is the skin temperature of the participant, and is influenced by a range of things. This signal does not show clear peaks that correlate with other physiological data.

Concluding, the baseline consists of the physiological data per signal and the characteristics of these signals. For the EDA signal this means that the signal is between 0.2 and 0.4 μS and that peaks in this signal at least have a value of 0.5 μS. For the BVP the signal varies between -3.5 and -3.6, with no clear peaks in the signal. The heart rate of the participant lies between 70 and 80 bpm while the participant is inactive. This signal can increase up to 120 when the participant is moving around a lot. The temperature of the participant was between 30 and 40 degrees during the experiment, however the average temperature was 29 degrees Celsius, meaning that this temperature could be lower in the winter. The overview of the baseline can also be found in Table 14.

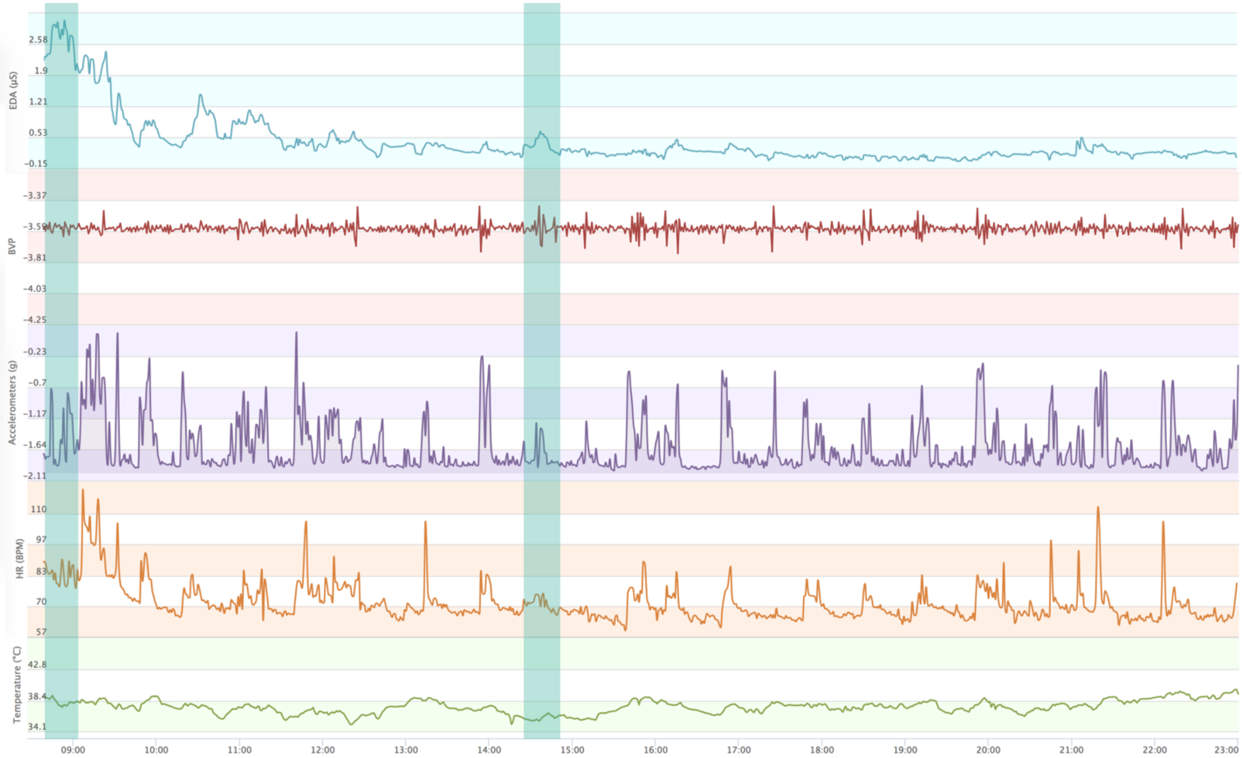
Physiological signal	Average	Minimum value for a peak
EDA (μS)	0.2 – 0.4	0.5
BVP	-3.5 – -3.6	/
Accelerometer	/	/
Heartrate (bpm)	70 – 80	/
Temperature (C)	30 - 40	/

Table 14 - Overview of the physiological baseline for the participant during experiment 2

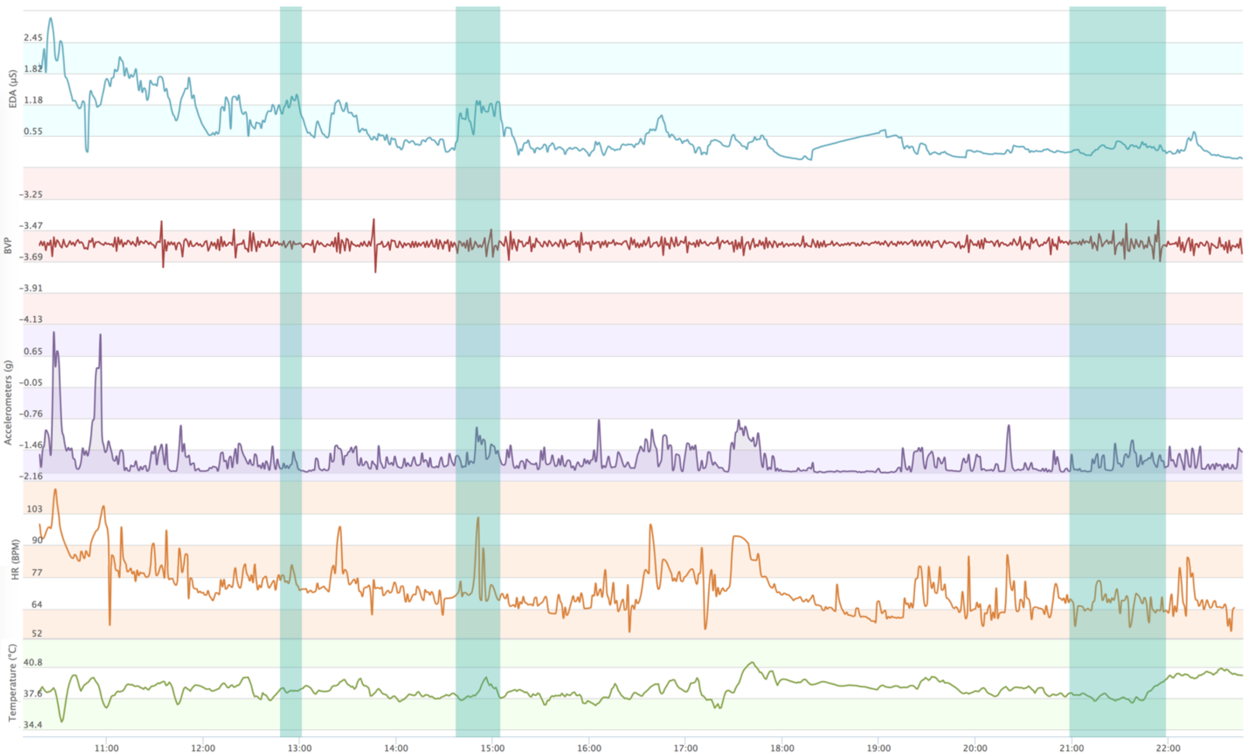
5.3. Baseline + Context mapping

The combination of the physiological data used for the baseline and the results from the context mapping is discussed and displayed in this section. In Figure 18, the physiological data per day is displayed, using the Empatica cloud application. The other two days, which are not used for the baseline, can be found at Appendix 10.4**Error! Reference source not found.**. On top of the physiological data, the events are marked, using the blue-green bars. The events are estimates by the participant and might differ a little, meaning that they could have started a couple of minutes earlier or ended a couple of minutes later.

Day 1 (Monday) with the two events marked.



Day 2 (Tuesday) with the three events marked.



Day 3 (Wednesday) with the three events marked.

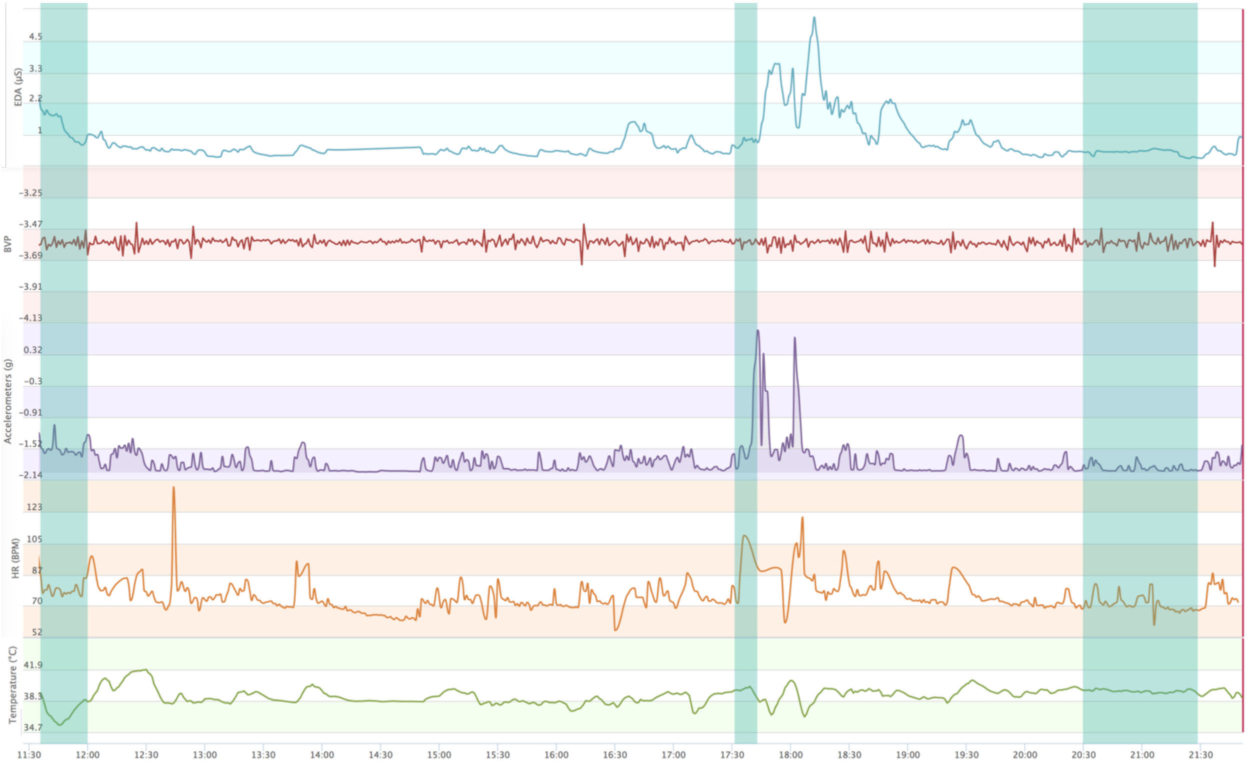


Figure 18 - Physiological data with the context mapped events marked for first three days

On first sight, it looks like the data corresponds with the marked events from the context mapping diary, which is show in the two examples from Figure 19. The events show a clear increase in electrodermal activity (EDA), while the hearth rate and temperature also slightly increase at these two specific events.

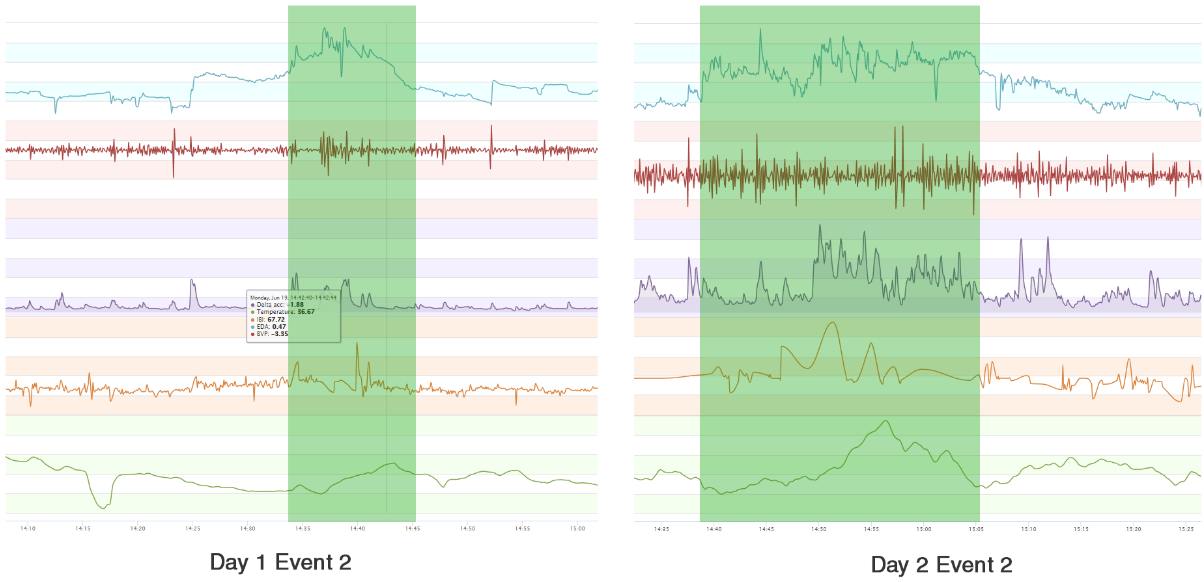


Figure 19 - Two example context mapped events

Like these two examples, a lot of the context mapped events that had impact on the participant show peaks within the physiological data. However, there are a lot more peaks present in the data than just the peaks which resulted from the context mapping. Figure 20 shows the peaks that are not related to context mapped events. This figure is created using the EDA explorer web interface on the data of day three (Wednesday). The Figure shows how there are clear peaks in the data which do not only show a clear peak in the EDA signal, but also in temperature and heart rate. This could have three reasons: First, the participant did not think that the emotional event that happened at that point was strong enough to write it down in the diary. Second, the peak was the result of something else than mood, for example activity (movement). Third, there is a big change in the environment of the participant, for example when she goes from inside the house to the supermarket (inside to outside) or when she takes a nap on the couch.

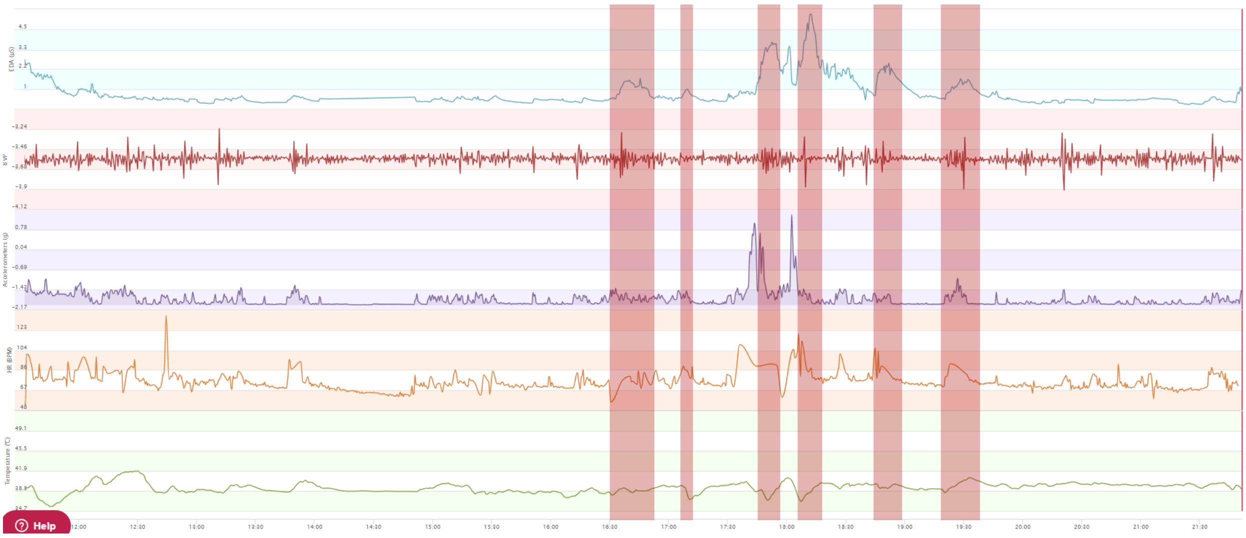


Figure 20 - Peaks without context map reference on day 3

With the context mapped peaks and the peaks without relation to a context mapped event it might not be possible to create a perfect algorithm which can detect all event or mood related peaks. However, it can be possible to detect all natural looking peaks and use the input of the participant to decide whether the peaks have an (negative) affective influence on the participant using the Pick-A-Mood method. But to do this, first we need an algorithm which can detect the required peaks.

5.4. Event detection

With the combination of recorded physiological data and the context mapping events from the diary it should now be possible to give the peak detection parameters used in the algorithm of the second part of this experiment. This algorithm should be based upon the results from the previous section, combining the baseline data with the self-reported emotional events.

The events which need to be detected by the algorithm need to show at least a peak in the EDA signal, while the other signals can increase the likelihood of something being a peak. Starting with the EDA signal, the context mapping peaks from each day show that any high impact event results in a peak which has an EDA of at least 0.50 µS over a longer period. Together with this minimum, the peak should also have a natural progression (natural peak), meaning that it should increase and decrease steadily and not just straight up (this might occur because of a false measurement or application bug).

The movement of the participant should also be considered, but unfortunately the baseline with the context mapping does not completely exclude movement from the affective events. There are context mapped events at which the accelerometer indicates a lot of movement, while there are also events at which the participant does not move at all. This makes it impossible to use the movement data to rate a peak, so this will not be used in the algorithm.

The heart rate does show similar behaviour to the EDA signal when looking at context mapped peaks. In most mapped events, the heart rate increases at the beginning, or shortly after the beginning, of the event and decreases afterwards or near the end. However, the heart rate signal does show this same behaviour even without being accompanied by an EDA peak, meaning that the heart rate signal on itself is less fitted to detect changes in the mood than the EDA signal. The heart rate signal can still be used to give extra weight to an EDA peak, making the system surer that there is an actual peak detected and that this peak is related to the affective arousal of the participant.

The temperature shows the same behaviour as the heart rate, but shows this behaviour to a lesser extent. The temperature measurements can be influenced by a lot more than just the emotional arousal of the participant, for example by a rise of external temperature (weather) or by movement activity of the participant. However, it could have been used in the same way as the heart rate signal when it's peaks were more related to the context mapped events, which they not always are. The temperature does tend to increase during events, but this looks not directly correlated with the peak detected in the EDA signal or the time stamps used in the diary. Therefore, the temperature will not be used in this version of the algorithm yet, but might still be suited for usage in future work versions.

5.5. Peak detection algorithm

With the information from the previous section it is possible to develop, a participant specific, version of the algorithm used to detect affective events in the physiological data of the participant. This algorithm should focus on the natural EDA peaks. The peaks in the EDA signal will last for seconds, sometimes multiple minutes before the signal decreases again. Therefore, it is not possible to use traditional peak detection methods, which mostly focus on one maximum or minimum. Another important part is the fact that the data is live streamed and therefore updated every fourth of a second. This makes it impossible to look at things like a derivative, for which a function is required beforehand.

This and the following chapter will investigate the available algorithms which can be used to detect these peaks. However, it should be noted that this treats the events from the context mapping as the ground truth, meaning that the algorithm will be tested using the event mapping results. This is done to make sure the application will generate results which can be used to investigate the effect of the mood based lighting on the current mood of the participant.

By using the context mapping as a ground truth, the system should at least be able to detect bigger events which the participant herself would also have marked as an emotional event.

5.5.1. Performance of the algorithms

Both the EDA Explorer and the Smoothed z-score algorithm (introduced and discussed in Chapter 2.3.2) are tested with two and a half days of data to show off and compare their performance on detecting peaks in the EDA signal. For the smoothed z-score algorithm a threshold of 20 is used together with an influence of 0.5, thereby a minimum amplitude was added of 0.5. For the EDA explorer, the standard settings are used with some small changes, which is a minimum amplitude of 0.5, an offset of 1, a filter frequency of 1, a filter order of 6, a max rise time of 4 and a max decay time of 4. In Figure 21 the peaks detected by the EDA explorer and the Algorithm are combined with the context mapping information per event, per day of the week. The context mapping per day also shows which Pick-A-Mood character was picked by the participant, resulting in an overview that shows how both methods respond to the participant's (peaks in) data and what the valence of each of these context-mapped events is. In addition to the visual results of the algorithms, the performance of both algorithm is also calculated and displayed in Table 15. In this table, the peaks detected indicate the total number of peaks detected by the algorithm. The true positives (TP) are the context mapped events that are detected as a peak by the algorithm. The false negatives (FN) are the context mapped events that are not detected by the algorithm. The false positives (FP) are the peaks that are detected by the algorithm, but are not marked as an event by the participant. The recall is the fraction of relevant retrieved events detected ($\frac{TP}{TP+FN}$) and the precision ($\frac{TP}{TP+FP}$) is the fraction of the retrieved relevant data.

Monday

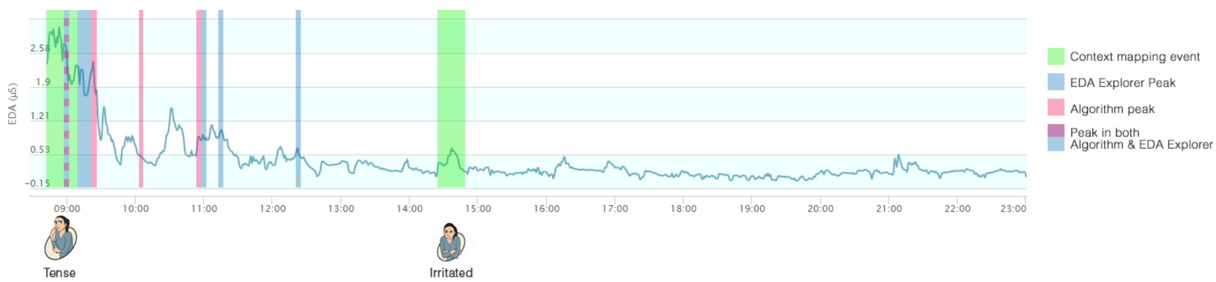


Figure 21 - Context mapping, EDA Explorer and Algorithm put on the EDA signal per day

	Z Score Algorithm	EDA Explorer
Peaks detected	23	22
True Positives	8	7
False Positives	15	15
False Negatives	6	7
Recall	57 %	50 %
Precision	35 %	32 %

Table 15 - Algorithm performance, Z score versus EDA explorer

5.5.2. The implemented algorithm

As can be seen in Figure 21 and Table 15, the EDA Explorer and the Smoothed z-score algorithm have almost the same performance in recall and precision. This shows that both algorithms perform about the same when detecting events that the participant classified as an emotional event. With this information, a choice should be made which of these two algorithms will be used for the peak detection system in the Android application. Both algorithms have their advantages and disadvantages. While the z-score algorithm is developed to work on real-time data, the EDA explorer algorithm is developed to identify peaks in the data after the measuring is done. This makes it much harder to implement the EDA explorer in a real-time system in comparison to the z-score algorithm. However, the EDA explorer is specially crafted to detect peaks in an EDA signal, while the Smoothed z-score algorithm is crafted just to detect peaks in a real-time signal. Thereby, the EDA explorer is the more widely known and tested by other researchers when it comes to detecting peaks in an EDA signal. In the end, the choice was made to use the Smoothed Z-Score algorithm in the android application mostly because the implementation of it was faster due to not needing a machine learning basis. The EDA explorer needed to be adapted to make the machine learning algorithms in the background also work in the Android Java based environment, while the EDA explorer algorithm is also harder to adapt to the context mapped events by the participant.

5.6. Atmosphere perception

At the start of the second part of the experiment, the atmosphere perception was tested for usage by the system. The Philips Hue API uses the values of Brightness, Hue, Saturation and Colour Temperature to create a specific colour with the light bulbs, like in the first user test. In total, there were four atmospheres tested with the participant. These atmospheres were tested in the order in which they are discussed here. To create the atmospheres, the following settings (based upon the cosy atmosphere of the first user test) were used in the Philips Hue API:

- Atmosphere 1. Hue 3500, saturation 200, brightness 254 and colour temperature 500.
- Atmosphere 2. Hue 3500, saturation 200, brightness 100 and colour temperature 500.
- Atmosphere 3. Hue 3500, saturation 200, brightness 190 and colour temperature 500.
- Atmosphere 4. Hue 3500, saturation 200, brightness 210 and colour temperature 375.

The four atmospheres tested are recreated and displayed in Figure 22. Note that these are recreated Hue settings and might look different in the living room. The overview of the resulting atmosphere ratings per dimension are displayed in Table 16.

Figure 22 - The four atmospheres tested in the second experiment (l.r.t.b. Atmosphere 1, 2, 3 and 4)

	Atmosphere 1	Atmosphere 2	Atmosphere 3	Atmosphere 4
Cosiness	1.67	6	5.67	3.67
Liveliness	4	1	4	3
Tenseness	1	1	1	1
Detachment	1.67	1	1	1.67

Table 16 - Atmosphere ratings per dimension per atmosphere

With the atmosphere ratings per dimension, the choice was made to use the fourth atmosphere for the neutral setting. This is because the fourth atmosphere came close to the normal lighting setting within the house. The only clear difference is the brightness of the lighting, which was set a little higher than the participant normally has within her living room. This is done to create a bigger difference between the cosy and neutral lighting. The cosy setting is an adaptation of the cosy setting used in the first user test. The first user test used Atmosphere 2, but in the bigger living room this did not produce a bright enough light to be used in a realistic setting. After some tweaking the participant rated Atmosphere 3 as the most positive atmosphere, combing a high cosiness rating with a high liveliness rating.

5.7. Mood adaptive ambient lighting

The lighting system consists of the android application connected with both the Empatica E4 and the three Philips Hue light bulbs. The system uses the event detection algorithm discussed in the previous section for event detection in the evening of day 3, 4 and 5 (Wednesday till Friday). The system was activated around 22:00 in the evening and remained turned on until 23:30, being active for at least an hour and a half per day.

The influence of the lights on the mood and feelings of the participant can be tested in two separate ways. First, it can be tested by combing the Pick-A-Mood results, the Empatica E4 streamed signal and the mapped events during the evening. The second way in which the influence of the lights on the mood could be tested is by using the conducted interviews to investigate the experience of the participant about the lighting and the usage of the lighting. This can be used because the lighting influences the mood and feelings of the participant, which can be reported in the interview. First the outcome of the peak detection algorithm will be discussed, after which the results from the interview is discussed.

In the previous section the algorithm is tailored to the baseline and the context mapping results of the participant. The algorithm uses for example a clear minimum, namely an EDA of 0.5, to start detecting a peak in the measurement. Unfortunately, after having deployed the full system for the second part of the experiment in the evening at day 3, the EDA data did not match the previously recorded Empatica E4 data. The streamed EDA data has an average of 0.05, while the recorded EDA data has an average between the 0.3 and 0.4. The reason for this is unclear, and unfortunately needed to be solved within one day, because the next day the system should at least detect the smaller peaks in the evening. The raw data from the application recorded sessions can be found in Figure 23.

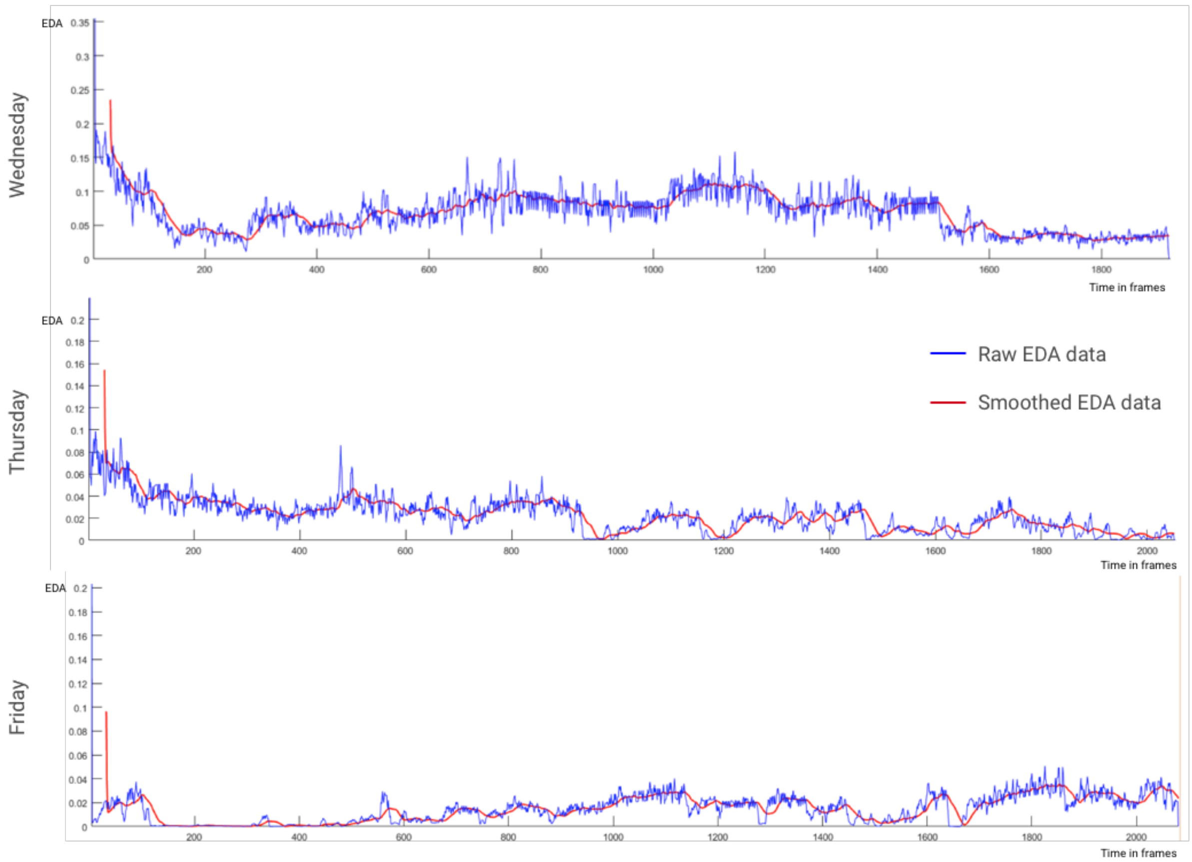


Figure 23 - E4 measurements in the evening, with the ambient lighting activated.

With the new EDA measurements from Wednesday evening at least one aspect of the algorithm needed to be changed, namely the minimum threshold of 0.50 needs to be lowered by a factor 10 almost. But after removing the threshold of 0.50, the algorithm still did not detect a peak in the EDA data stream. The data was also checked for peaks with the EDA explorer, but this did not give any better results. The data can be seen in the graphs from Figure 23. The figure shows that the data has a lot more noise in comparison to the data from Figure 21. These fast changes in data cause the algorithm to not be able to detect natural peaks. Which results in not being able to use the raw data to detect peaks. Therefore, a smoothing function is used on the raw EDA signal, taking the average per second, resulting in the red line which is present in Figure 23. This red line shows an EDA signal which comes closer to the previously recorded EDA data. With this new average data per second, the algorithm can detect certain peaks in the signal (with the threshold of 0.50 removed). These results of the adapted version of the algorithm can be seen in Figure 24. Note that this Figure also shows the results of Wednesday, but these are the algorithm results calculated afterwards (and not real-time), to see if the new adapted algorithm would function. The Pick-A-Mood results from the Wednesday are therefore not precisely mapped on the timeline, but do give a good overview about how the evening progressed without having detected any peaks by the system.

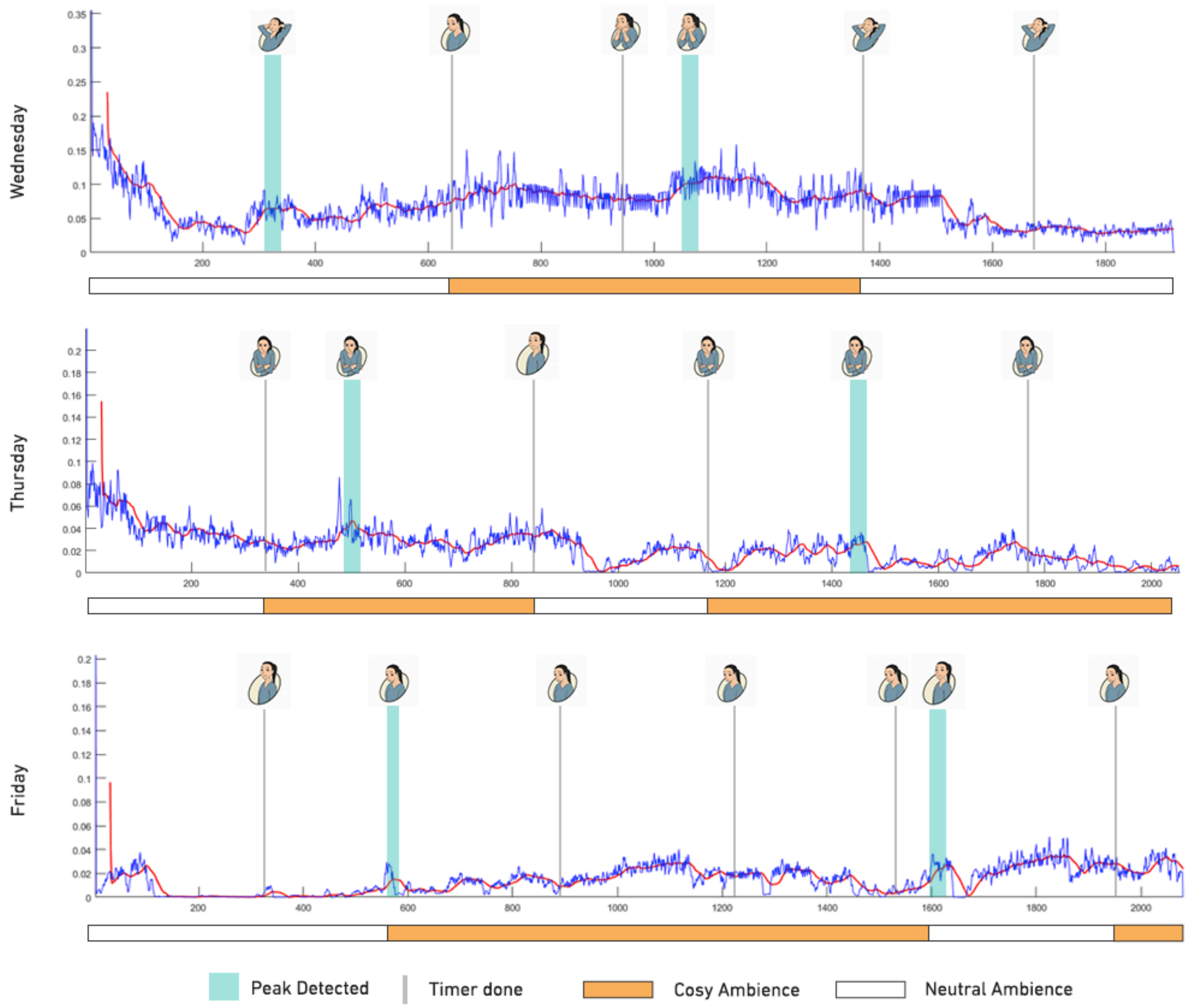


Figure 24 - Visual overview of the light system with peak detection and two ambiences.

In the experiment the lights only responded when the Pick-A-Mood interface was used by the participant, which happened after the timer was done or a peak was detected. In total a peak was detected two times per evening, showing that the participant experienced arousal according to her EDA data. Figure 24 shows how a negative choice in Pick-A-Mood leads towards a cosy ambience (lighting setting). However, this cosy ambience does not seem to influence the next Pick-A-Mood choice. After changing the ambient lighting to the cosy setting, the mood remained in the same negative valence as before for at least 30 minutes. The self-reported mood could even be negative for almost an hour, which showed no influence by the cosy ambience. Concluding, the data does not show an improvement in mood by the change in ambient lighting.

5.8. Interview results

With the information gathered from the Empatica E4 there is already a lot of data on the user test discussed in this chapter. The only things that is missing is the experience and effect of the ambient lighting on the participant, which this chapter will discuss using the qualitative data gathering interview set up in Chapter 3.5.2. This section will start by focussing on the process and the interactions during the user test, after which it will continue with the results according to the participant. The interview results are analysed using the qualitative analysis methods meaning condensation and meaning interpretation, which are discussed in the procedure.

5.8.1. The process

The participant said nothing strange happened during the evenings at which the lighting system was activated. It were normal evenings, there was not a night on which something out of the ordinary emotionally happened. In the evening the participant normally sits in her chair, watching television or reading a book, which she also did in the evening of day 3, 4 and 5. She noticed that she was in a positive mood during the three evenings and did not have negative feelings at any point. Despite her positive mood, she did pick multiple negative moods in the Pick-A-Mood interface, but this was only partly focussed on her current mood. This contradiction was discussed during the interview. It appeared that when she picked a mood in the Pick-A-Mood interface during the evening, she focussed not only on how she felt at that moment, but also on how the room looks. She took a minute or two to take in the ambience in the room and used this to pick a mood. For example, when the lighting was less bright she would associate this with a more negative mood, while she felt more positive than the mood she picked according to her interview answers.

The participant noticed that there were a couple of different light settings. After the first two evenings, she thought there were at least three different colour settings while there were only two settings. During the in-depth interview, the researcher explained that when the lights changed slowly, they created a range of light settings to gradually change into the new light setting, which the participant described as other light settings. She described the cosy light setting as a positive atmosphere in the Vogels Atmopshere Questionnaire, but she picked a negative mood when she sat alone in the living room. It appeared to be that the lower brightness of the lights negatively influenced her mood, because it made her less active.

The biggest struggle the participant experienced during the user test was with the Pick-A-Mood interface on the Android Application. While she had used the Pick-A-Mood interface already in the diary, it proved to be more challenging to use it to report her current mood (which was not related to a specific event). She struggled with what she should focus on when choosing a mood, she wanted to pick the mood which fitted best to the current situation and not always to her current mood state. This is something which was discussed during the multiple interviews at the end of the week, but is not something she changed during the user tests. Even during the last evening, she says that she first looks at the ambient lighting around her before choosing a Pick-A-Mood option. She remarked that she noticed during the user test that she picked a lot of the same icons from the Pick-A-Mood interface, which made her doubt her choices. In the end, she decided that it should be “normal” to have the same mood or emotion during a longer period, so this did not change her Pick-A-Mood icon choice.

5.8.2. The results

The participant noted that she thought that the lights would not influence her mood a lot, but she did mention that the darker light made her sadder (“depressing dark lights” she called them). She did like the way the lights could quite easily transform the ambience within the room with just a little change in brightness or colour. The results indicate that the ambient lighting influences the mood of the participant, when it automatically changes during the evening. However, this does not mean that the system works in combination with her mood. She did not notice that the lights changed according to the mood she picked, but she thought they changed randomly. This might have been due to the slow changes after picking a mood, resulting in a new light setting more than a minute after she had picked a mood in the interface. Because of this, she also did not notice light changes due to a positive or negative mood she picked. She did not always like the changing lighting. This had two reasons, first the change in lighting reminded her that she needed to fill in the Pick-A-Mood interface, making her think about what she was going to pick. Second, because she felt that she became more restless because something was changing inside her living room, but outside her control.

After using the lighting system for three evenings, the participant was asked which part of the user test she liked and which part she did not like. Starting with the lights, she noticed that the ambient lights influenced the ambience within her living room a lot. She felt that a brighter, cosier setting will made her feel more comfortable resulting in a positive influence on her mood, but when the light became too bright or too dark, it negatively influenced her mood. The participant recommended that the system might be more effective when it was used to empower the regular lighting. The regular lighting being the lighting which is already present in her living room, which could be enhanced by adding the ambient lighting colours as an accent.

Furthermore, the participant said that she would like the system more when it could be used without the Pick-A-Mood application. The experience would have been better when she does not have to think about picking moods. Her ideal situation would be a situation in which the lighting changes without her noticing and when it would be in addition to the current lighting. That way, she expects her mood to be positively influenced because of the lighting and without getting restless or irritated because of having to pick a mood every so much time. In conclusion, when the system works without continuously needing to pick a mood and when the system can be added to the existing lighting, she wants to use it and even recommends it for friends.

6. Discussion and Limitations

The discussion is separated into three parts. The first two parts will discuss the choices and limitations that happened during the execution of the first and second experiment. The last part discusses the choices and limitation during the full research and how these influenced the final results.

6.1. Experiment 1

For the induction of the sad mood, the Gross and Levenson (YEAR) movie set was used. The movie clip from “Lie to me” was used to induce the sad mood. This sad event did not induce a measurable mood at the participants, because the effects only lasted a maximum of two minutes. The participants also reported that the mood induction through the video did not have a lasting influence on them. They became a sad, but it is likely that it did not last because they had no real (long) emotional connection with the characters in the movie scene. But this reason is not investigated in this research.

The recording of the EDA signal started directly after the video, resulting in not having any EDA data per participant before the start of the video. Because of this, the effect of the video on the EDA signal cannot be investigated. Only the different between during the video and after the video was therefore investigated in the results of experiment 1.

The living room created for the first user test was rated high on the 7-point scale on cosiness and liveliness, but did lack some aspects of a normal living room. For example, the created living room did not have a normal window and was rather small. To test the influence of lighting on the mood, the next test needs to be done in an existing living room. This has two reasons, first the effects of lighting within a person’s own living room have not been tested yet, and second the participant has his or her own personal emotional attachment to the living room which might change the effects of the lighting. These reasons will influence the effect of the ambient lighting and should be tested before the ambient lighting is used. This can be done by using the same questionnaire for the atmosphere perception as is used during the first test.

Recording the physiological data during the first experiment did not always go as smooth as possible. There were two errors during the experiment, which resulted in the need to have the participant restart the Empatica E4 wristband. This had two reasons, first the application could not always handle when it went from portrait mode to landscape mode or vice versa. Second, the Bluetooth connection of the Empatica API could disconnect the device when the connection was lost for only a short period. These two errors resulted in the need to instruct each participant before the experiment to turn on the E4 when it disconnected. This might have influenced the data (created extra arousal peaks), but there are no clear outliers detected that occur with recorded errors. An error occurred on average once per participant.

6.2. Experiment 2

The experiment is conducted with only one participant, meaning that the experiment cannot give any significant results based upon events that occurred at multiple participants. However, by having conducted extensive qualitative interviews with the one participant, still enough in-depth information is gathered about the influence of the ambient lighting on the mood of the participant. These results are mostly used to investigate to see if and how the system should respond to the manual and physiological input of the user, and how the user responds to the changes in ambient lighting. Like mentioned in Chapter 5.8, the results with the qualitative results should be used to set up a quantitative follow-up research focused on more empirical data. Which could be used to verify the results of this research and hopefully make them applicable to use cases with multiple elderly participants.

This experiment uses the context mapping diary as a ground truth, meaning that the algorithm chosen to be used in the Android application was fitted to the data measured in the first part of the experiment. This can work when using only one participant, but when developing the system for a bigger number of users it does not. The choice to still use the context mapping diary as a ground truth for the system during the last three evenings is made because of the goal of this research. The goal is to focus on how the ambient lighting based upon changes in mood could influence the mood of the user. By using the diary as the ground truth, a peak detection algorithm was chosen that could detect the bigger emotional events in the life of the participant. These were the events that the participant experienced and recognized as a (big) emotional events, which does not mean that these are the only emotional events that occurred or that this is the only emotional arousal the participant experienced during the day.

Another result that showed that the context mapping is not ideal in this situation, is the number of mapped events in the diary. There might have been a lot of different emotional events during the day which the participant did not notice or did not think were big enough to write about. During one of the interviews the participant mentioned that she did feel a little sad during the day. When asked about how and why she did not write these kinds of feelings in the dairy, she responded that she was not sure when she felt this precisely and how to describe this feeling. This feeling of sadness is something which the system should be able to pick up to improve the mood of the participant. However, there was no actual peak or change in the EDA signal detected that could match this specific mood change. If re-doing this experiment, the diary could be adapted to not only ask for event based input, but to also use other methods of gathering data. For example, a daily timeline with all events that happened during the day, including movement like going to the supermarket.

During the evening measurement of the second experiment, the diary was not used anymore to get a context with the physiological data. In these evenings, the lighting system was tested based upon the previously defined algorithm. However, during these evenings the participant did not report any big emotional events. The evenings were discussed in the interview conducted afterwards, but trying to remember afterwards does not always give the full picture (the participant could have forgot about a specific event for example). In the second user test the participant explained that there were no real events during the evenings, that she remembered. Even when the diary would have been used during the evening, it would not result in many useable events, according to the participant.

One of the biggest points of discussion during this research is the use of the smoothed z-score algorithm used to detect peaks in the streamed EDA data. Like mentioned before, the diary was used as a ground truth, meaning that the used algorithm was tested on the context mapped events. This resulted in a peak detection algorithm that was (probably) over fitted on the data of this specific person, making it not useable for other users. The reason for the use of this over-fitted algorithm is to still be able to test the full setup of the system, including lights that respond to the user's mood. This resulted in a lot of quantitative data that can be used to rate the experience of the user, but also to rate if the system is able to improve or change the mood of the user by changing the ambient lighting.

One of the main disadvantages of the EDA explorer algorithm is that it cannot be easily used with real-time data. However, this might be solved when the EDA explorer is used for smaller parts of the data. When cutting the data into smaller parts, it might be used in the EDA explorer. The only disadvantage of this method is that it might remove peaks at the cut-off between the smaller parts of data, but when the smaller parts are not too small this might still be useful for an easily implementable solution.

Thereby another problem arose, namely the data measured with the E4 during the days using the recording method differed a lot from the data gathered in the evening using the streaming mode (by a factor 10 or more). This could have multiple reasons, ranging from the data handling by the Empatica API or the data processing by the application itself to the device itself being broken and therefore not able to stream the correct data. The real reason for this difference remains unknown and is currently under investigation by Empatica, after this was reported to their helpdesk. Because of the difference in data it could be said that the algorithm, that was created for the recorded data, is not applicable anymore for the peak detection. The measured values changed, changing the thing the algorithm is based upon. However, the participant indicated that no actual emotional events happened during the night, which makes it not certain if the algorithm did indeed not work anymore or if it still worked on the lower data values.

6.3. In general

During this research, a choice needed to be made to either focus on developing a full functional system or focus on one or multiple individual parts (for example, the peak detection algorithm). The choice was made to keep a broad focus and investigate how a system that could measure and influence the mood of the participant could be developed, which resulted in a working and tested prototype. This means that sometimes not the most optimal solution to a problem was chosen, but a decision was made to use a solution that focusses more on the final goal (answering the research question) and still functions. This would remove a part of the scalability of the system (for other users than just this one participant), but could still be used to answer the research questions. For example, as a replacement for the machine learning methods for detecting moods, a self-reported mood measurement tool was used, namely Pick-A-Mood. This method is developed by researchers by comparing it to mood measuring tools that have existed since the 1980's, proving that it is a validated and easy to use method to let a user report his or her mood. However, this still requires the user to report their own mood, because the system cannot know in which mood the user is without having the Pick-A-Mood information inserted first. This was a functional setup, but not always the most optimal one. In the last user test, the participant noted that the setup using Pick-A-Mood made her a little restless. During the whole evening, she was focussed on the Android application and which icon she should select next in the Pick-A-Mood interface.

By choosing to keep a broad focus, this research transformed more into a proof of concept. Meaning that the focus is on testing the concept and proving that ambient lighting can improve the mood of a person. This way the current version of the system cannot be deployed at multiple elderly, but it does show promising results for future research.

From the E4 measurement data in the first and second experiment test only the EDA signal is used to look at the mood of the participants. However, it is possible to not only use the EDA signal, but also look at the heartrate, temperature and accelerometer data. By combing the information from all the E4 sensors, it can be possible to more accurately map the mood of the participants. Therefore, in the next version the system should at least save all the data which it receives from the E4 and not only save the EDA data like it did during the first user test.

A big part of this research was focussed on verifying the results from other research. This was done by reproducing several experiments done in related research in the first experiment. During the first experiment, three ambiences were tested to investigate if the findings from other research could be recreated in a new setting. This resulted in having a cosy atmosphere which should be able to positively affect the mood of the person in the room. In the second user test, this atmosphere was recreated and rated by the participant, after which it was used in the used algorithm. However, in the interview the participant noted that the valence of the atmosphere did not affect her in the same way as before. In the evening, especially when she was alone, she liked the brighter ambiences, because it kept her both positive and active. The participant estimated that when the cosy atmosphere was added as an addition to her regular lighting it would indeed improve the valence of the room and her mood. This shows that the atmosphere test from Vogels can have a different outcome when the user rates the atmosphere at a different part of the day or in a different social setup (with or without people around). The difference between the atmosphere perception only came up when measuring for more than a couple of minutes, proving the benefits of measuring over a longer period.

7. Conclusion

The final chapter of this research contains a general conclusion based on the work done throughout this research. This chapter focusses on answering the research goals and questions stated at the beginning of this document (Chapter 1.1) and examines if these questions are answered in this research. This will be done per sub-question, ending with the main research question and a general conclusion.

Which mood measuring method can be best used to measure the effect of light on the mood of the elderly?

To develop the mood-adaptive lighting system, this thesis started with investigating the different methods which can be used to measure (the effect of the lighting on) the mood of the elderly. The different methods available which could be used for this purpose, are facial expressions, movement analysis, speech recognition and bio signals. The choice was made to use physiological signals, consisting of the blood volume pulse, the heart rate, the electrodermal activity, the temperature and the movement of the user.

The main reason for this is that the other mood measuring methods require a bigger setup in comparison to using physiological signals. Facial requires multiple camera's to be able to record the face of the participant during the day, while the participant might also move out of the field of view of the cameras. Speech recognition requires multiple microphones and more importantly requires the participant to have a conversation. Unfortunately, the target group (the elderly) have lonely moment and moods in which they do not have a conversation in the evening at all. Movement analysis is a method which is used for specific movements and used mostly for bigger groups of people instead of focussing on one person.

The physiological signal measuring is tested within the first experiment. The EDA signal was recorded for each of the different participants and stored in the developed system, to be later used for peak detection.

How can the measured signals be mapped to mood models?

With the decision to use physiological data for mood measuring, existing mood models could not be used any more. This is because physiological data on its own cannot (yet) be used to determine in which (specific) mood or affective state a person is. However, the electrodermal activity from the E4 can and is used to find (big) changes in a person's arousal, which can be detected as peaks in the electrodermal (EDA) signal. In the first experiment this is tested and as Table 11 shows the signal responded to what happened around the participant. While the EDA signal did not respond in the neutral lighting setting, it did change when the lighting around the participant changed.

The valence of these detected changes in arousal cannot be derived from the physiological data automatically. To derive a specific affective state from the signal either a machine learning algorithm is used or a self-reported mood method needs to be added to the peak detection system. In this research, the choice was made to use the self-reported mood measurement method called Pick-A-Mood, which consists of eight mood states from which the user needs to pick one. This choice was made because developing and using a machine learning algorithm would shift the scope of this research into the development of mood in a physiological signal, while the focus is on the effects of a mood controlled ambient lighting system on the mood of the participant. The self-reported measurement might not work in the long term, but to proof the concept of ambient lighting that can improve negative moods it is good enough.

In both the first and second experiment the self-reported Pick-A-Mood method is used to gain information about the valence of the participant's mood. In the second experiment the system is able to detect changes in the arousal through the peak detection algorithm, after it has been tailored to the physiological data and context mapping results of the participant. By combining the changes in arousal with Pick-A-Mood it is possible to get a specific mood for each big change in the EDA signal.

What is the user experience and how do the elderly respond to the ambient lighting in the room?

The system only interacted with the user at very specific times, namely when a peak was detected or when the timer had passed. At these moment, the GUI would light up (with a white background) and tell the user what to do. After the user is triggered to interact with the system (by the screen turning white), the system displays the eight characters from which the user needs choose one. After choosing a character, the screen would go back to the idle state, which is a black screen. During the second experiment, the participant reported that she liked the interaction with the system when selecting a Pick-A-Mood character. She noticed the system turning white quite fast and was able to always give her self-reported mood as input. However, she also experienced a restlessness by using the system and seeing the ambient lighting change around her. She needed to pay attention to two things during the evenings, namely if the screen turned to white and what her current mood or affective state was. The participant reported that she would always try to keep the screen in the corner of her eye, which made her restless. Thereby, she also did not always know what character she was going to pick when the screen asked her to. To counter this indecisiveness, she used the idle time to already think about which character she was going to pick next.

In what way does the lighting in the living room need to change to improve the mood of the elderly?

The ambient lighting used by the system to improve the mood of the elderly is based upon the research by Kuijsters et al. (2015). In this research, they have investigated the effects of different colours and brightness of ambient lighting on the elderly. The results from this research are used in both experiments, and show higher perception ratings for the liveliness and cosiness within the living room. In the first experiment, the rooms with positive affective ambient lighting are experienced by the test participants as a positive environment, and the rooms without this positive affective ambient lighting are experienced by the test participant as less positive environments. By using yellow or orange ambient lighting colours, the participants will perceive the room as more cosy and lively in comparison to other colours. An activating setting, with more bright and blue coloured lighting, is also perceived as livelier and cosy in comparison to a neutral white setting. However, the activating setting does not show the same high scores for the cosiness and liveliness in comparison to the cosy setting with the yellow and orange lighting.

On the other side, this research could not provide a data based conclusion on the effectiveness of these different types of lighting. The cosy ambient lighting setting that scored the highest on cosiness and liveliness did not influence the mood of the participant in both experiment done in this research. The results from both experiment 1 and 2 do not show that the cosy lighting setting has a more positive influence on the mood in comparison to other ambient lighting settings.

How can a system be developed to automatically measure and increase the mood of the elderly by changing the lighting in their living room?

The, in this research, developed system can detect arousal changes in the user's physiological data and automatically respond to these changes by asking the user for the valence of these changes. This system relies on the self-reported mood input of the user and does not automatically measure and increase the mood of the user, which was the goal of the main research question. This could be achieved by extending the existing research on mapping physiological data to mood states or by using another more intrusive mood measurement method like facial expression recognition.

In this thesis, the first steps were made towards a system that can automatically detect (negative) affective states and adapt the ambient lighting based on these states. The system uses an algorithm to detect arousal peaks in the physiological data recorded with the Empatica E4, after which it requires the input of the user to get the valence of the detected arousal change. The user is required to use the Pick-A-Mood self-reported mood measuring tool to add a valence to the detected peak in electrodermal activity.

To develop this system, the physiological data of one person has been measured for a two and a half day including the emotional context. By combing this data (also called the baseline) with a context, the peak detection has been tailored to this specific user. After this tailoring, the system was tested for three evenings with the ambient lighting to improve the mood if necessary. The physiological and self-reported mood measuring results do not show a direct influence of the lighting on the mood of the participant. However, the participant was also interviewed using qualitative data gathering interviews to get as much information about the experience and the effects of the system as possible (and not solely rely on the measurement). The participant mentioned during the interviews that the system can change the ambience of her living room, changing it into a (for her) cosier and positive environment. This also affected the current mood of the participant. The participant noted that she thinks the system would influence the mood of the user and that it might be, with a few adaptions (no Pick-A-Mood and function as an addition to the existing lighting), useful for people that she knows.

8. Future work

In this document, several choices are made and discusses during the development of a mood adaptive ambient lighting system. In this last section, the biggest recommendations for future development and research are discussed.

At the start of the research a definition is given for what a person's mood and an affective state how they are related to each other and other emotional states, like emotions. During the research however, the term mood changed into a longer lasting emotion instead of being an actual mood. A mood is the long lasting affective state, with or without clear reason, but at the end of the research the term mood is more focussed on shorter affective states with a clear reason. This is because in the related literature the term mood is used to describe different affective states, which not always means that they focus on the same affective state. With the context mapping for example, the focus has shifted from a (day-long) mood to a longer affective state, maybe even a long(er) lasting emotion, that resulted from an identifiable event. This should be noted especially for future work, because it is important to make clear what kind of affective state is focussed in an affect-focused research and what kind of affective state was focussed on in the used literature.

Like mentioned in at the start of the discussion, Pick-A-Mood was used throughout this research as a tool for measuring the mood of the different participants. However, for future work this is not the optimal solution. The user input should be replaced by an algorithm that can automatically detect the different mood states in which the user can be. This can be done by using a machine learning algorithm, like the one used by Picard et al. in their one subject research (2001). If this still proves to be troublesome, it might be even necessary to use another mood measuring method like facial expressions. These methods of course have other disadvantages which need to be considered before deciding on the best method to use for an ambient lighting system that does not require manual input by the user.

In the current system, the smoothed z-score algorithm is used instead of the more established EDA explorer. For future use however, the EDA explorer is recommended when detecting the arousal caused peaks in the EDA signal. In future research, it would be useful to extend the peak detection algorithm to indicate in which mood the user is, based upon the physiological data of the user. The measurements from Figure 18 show that not only the EDA signal changes during an emotional event, but also the temperature, heartrate and movement measurements start respond. By using the whole range of physiological signals, it might be possible to create a machine learning algorithm that can classify these measurements into specific moods. Maybe using the temperature and heart rate measurements to put more weight to a detected peak in the EDA signal.

Thereby, in total there were 15 minutes of physiological measurements recorded per person for the first 20 participants, which resulted in a wide range of EDA. The second user test focussed on one participant for five full days, for 63 hours of measuring in total. Even with the 63 hours of recording the system did not yet find every kind of emotion or mood of the user. To be able to detect all kinds of (negative) moods the system should monitor a user for more than a week, improving with more physiological data if there is a machine learning algorithm supporting it.

9. Bibliography

4TU Emphatic Lighting. (2017, Januari 30). *Empathic Lighting.* Retrieved from 4TU Federation: https://www.4tu.nl/nirict/en/Research/Empathic-Lighting/

Affectiva. (2016). *Affectiva Affdex*. Retrieved February 4, 2017, from Affectiva: http://www.affectiva.com/solutions/affdex/

Alasuutari, P. (2010, June). The rise and relevance of qualitative research. *Social Research Methodology, 13*(2), 139-155.

Ali, M. R. (1972, September). Pattern of EEG recovery under photic stimulation by light of different colors. *Electroencephalography and Clinical Neurophysiology*, 332-335.

American Heart Association. (2016, October 12). *Target Heart Rates.* Retrieved July 18, 2017, from Heart.org: http://www.heart.org/HEARTORG/HealthyLiving/PhysicalActivity/FitnessBasics/Target-Heart-Rates_UCM_434341_Article.jsp#.WW3eYsaB1yA

Association for Contextual Behavioral Science. (2017). *Toronot Alexithymia Scale (TAS-20).* Retrieved April 28, 2017, from Contextual Science: https://contextualscience.org/TAS_Measure

Bedrosian, T. A., & Nelson, R. J. (2013, July). Influence of the modern ligh environment on mood. *Molecular Psychiatry, 18*, 751-757.

Beyond Verbal. (2017). *Beyond Verbal.* Retrieved February 6, 2017, from Beyond Verbal - The emotions analytics company: http://www.beyondverbal.com/

Biernacki, P., & Waldorf, D. (1981). Snowball Sampling, Problems and Techniques of Chain Referral Sampling. *Socialogical. Methods & Research, 10*(2), 141-163.

Botek, A.-M. (2014). *Loneliness in the elderly*. Retrieved February 23, 2017, from Agin Care: https://www.agingcare.com/articles/loneliness-in-the-elderly-151549.htm

Boucsein, W. (2012). *Electrodermal Activity.* Springer Science+Business.

Boyce, P., & Barriball, E. (2010). Circadian rhythms and despression. *Aust Farm Physician, 39*(5), 307-310.

Carlson, R. G., Siegal, H. A., & Falck, R. S. (1995). Qualitative Research Methods in Drug Abuse and AIDS Prevention Research: An Overview. In E. Y. Lambert, R. S. Ashery, & R. H. Needle, *Qualitative Methods in Drug Abuse and HIV Research* (Vol. 157, pp. 6-26). Rockville: NIDA Research Monograph.

Center for the study of Emotion and Attention. (2001). *The international affective picture system: Digitized photographs.* Gainesville, Florida: The center for Research in Psychphysiology, University of Florida.

Cohen, D., & Crabtree, B. (2006, July). *Qualitative Research Guidelines Project.* Retrieved May 22, 2017, from Qualres: http://www.qualres.org/HomeSemi-3629.html

Crane, E., & Gross, M. (2007). Motion Capture and Emotion: Affect Detection in Whole Body Movement. *Affective Computing and Intelligent Interaction., 4738*.

Custers, P., de Kort, Y., Ijsselsteijn, W., & de Kruiff, M. (2010). Lighting in retail environments: Atmosphere perception in the real world. *Lighting Research & Technology, 42*, 331-343.

Desmet, P. M., Vastenburg, M. H., & Romero, N. (2016). Mood measurement with Pick-A-Mood: Review of current methods and design of a pictorial self-report scale. *Journal of Design Research, 14*(3), 241-279.

Desmet, P. M., Vastenburg, M. H., & Romero, N. (2016). *Pick-A-Mood manual: Pictorial self-report scale for measuring mood states.* Delft, NL: Delft University of Technology.

Ekkekais, P. (2012). Affect, Mood and Emotion. *Measurement of Affect, Mood, and Emotion*, 321 - 333.

Empatica Inc. (2016, December 05). *What should I know to use EDA data in my experiment?* Retrieved February 12, 2017, from Empatica: https://support.empatica.com/hc/en-us/articles/203621955-What-should-I-know-to-use-EDA-data-in-my-experiment-

Field, A. (2013). *Discovering Statistics Using IBM SPSS Statistics.* Sage Publications Ltd.

Frijda, N. (2009). Mood. In D. S. Scherer, *The Oxford companion to emotion and the affective sciences* (pp. 258-259). New York: New York: Oxford University Press.

Garbarino, M., Lai, M., Bender, D., Picard, R. W., & Tognetti, S. (2014). Empatica E3 - A wearable wireless multi-sensor device for real-time computerized biofeedback and data acquisition. *EAI 4th International Conference on Wireless Mobile Communication and Healthcare*, (pp. 39-42).

Gaver, B., Dunne, T., & PAcenti, E. (1999, Feb). Design: Cultural probes. *Magazine interactions, 6*(1), 21-29.

Gouizi, K., Reguig, F. B., & Maaoui, C. (2011). Emotion recognition from physiological signals. *Journal of Medical Engineering & Technology, 35*(6), 300-307.

Gross, J. J., & Levenson, R. W. (1995). Emotion elicitation using films. *Cognition and Emotion, 5*(1), 87-108.

Haag, A., Goronzy, S., Schaich, P., & Williams, J. (2004). *Emotion Recognition Using Bio-sensors: First Steps towards an Automatic System.* Sony Corporate Laboratories Europe. Berlin: Springer-Verslag.

Haag, A., Goronzy, S., Schaich, P., & Williams, J. (2004). Emotion Recognition Using Bio-sensors: First Steps towards an Automatic System. *ADS 2004: Affectie Dialogue Systems* (pp. 36-48). Berlin: Springer, Berlin, Heidelberg.

Huldtgren, A., Katsimerou, C., Kuijsters, A., Redi, J. A., & Heynderickx, I. E. (2015). Design Considerations for Adaptive Lighting to Improve Seniors' Mood. *International Conference On Smart homes and health Telematics* (pp. 15-26). Geneva: Springer.

iMotions biometric research platform. (2016). *iMotions GSR Pockter Guide.* Retrieved June 26, 2017, from iMotions: https://imotions.com/wp-content/uploads/Guides/iMotions_Guide_GSR_2015.pdf

International Commission on Illumination. (1987). *International Lighting Vocabulary.* Vienna.

Jang, E. H., Park, B. J., Kim, S. H., Eum, Y., & Sohn, J. H. (2014). A Study on Analysis of Bio-Signals for Basic Emotions Classification: Recognition Using Machine Learning Algorithms. *International Conference on Information Science & Applications (ICISA)* (pp. 1-4). Seoul: IEEE.

Jean-Paul. (2014, March 25). *Peak signal detection in realtime timeseries data.* Retrieved June 8, 2017, from Stack Overflow: https://stackoverflow.com/questions/22583391/peak-signal-detection-in-realtime-timeseries-data/22640362#22640362

Junior, P. T., & Filgueiras, B. L. (2005). User modeling with personas. *CLIHC '05 Proceedings of the 2005 Latin American conference on Human-computer interaction* (pp. 277-282). Cuernavaca: ACM New York, NY.

Küller, R., Mikellides, B., & Janssens, J. (2009, April). Color, arousal, and performance—A comparison of three experiments. *Color research & application, 34*(2), 141-152.

Kaikkonen, A., Kekäläinen, A., Cankar, M., Kallio, T., & Kankainen, A. (2005, November). Usability testing of mobile applications: a comparison between laboratory and field testing. *Journal of Usability Studies, 1*(1), 4-16.

Kaiser, P. K. (1984, March). Physiological response to color: A critical review. *Color Research & Application, 9*(1), 29-36.

Kandel, E. R., Schwartz, J. H., Jessell, T. M., Siegelbaum, S. A., & Hudspeth, A. J. (2000). *Principles of Neural Science* (Vol. 5). New York: McGraw-Hill Health Professions Division.

Knez, I., & Kers, C. (2000). Effects of indoor lighting, gender, and age on mood and cognitive performance. *Environment and Behavior, 32*, 817-831.

Kuijsters, A., Redi, J., de Ruyter, B., & Heynderickx, I. (2015). Lighting to Make You Feel Better: Improving the Mood of Elderly People with Affective Ambiences. *PLoS ONE, 10*(7).

Kuijsters, A., Redi, J., de Ruyter, B., Seuntiëns, P., & Heynderickx, I. (2014). Affective ambiences created with lighting for older people. *Lighting Research & Technology, 47*, 859-875.

Kvale, S. (1996). *InterViews: An introduction to qualitative research interviewing.* Thousand Oaks, California : SAGE Publications.

Lang, P., Bradlet, M., & Cuthbert, B. (2001). *International affective picture system (IAPS): Instruction Manual and Affective Ratings.* (Vols. A-5). Gainesville, Florida: The Center for Research in Psychophysiology, University of Florida.

Lee, C. M., & Narayanan, S. S. (2005, March). Toward detecting emotions in spoken dialogs. *IEEE Transactions on speech and audio processing, 13*(2), 293-303.

Lewy, A. J., & Sack, R. L. (2009, July 01). The Dim Light Melatonin Onset as a Marker for Orcadian Phase Position. *Biological and medical rythm research*, 93-102.

MacEvoy, B. (2015, January 25). *Color Temprature.* Retrieved April 3, 2017, from Handprint: http://www.handprint.com/HP/WCL/color12.html

Mayer, J. D., Allen, J. P., & Beauregard, K. (1995). Mood inductions for four specific moods: A procedure employing guided imagery vignettes with music. *Journal of Mental Imagery, 19*, 151-159.

Mikellides, B. (1990). Color and physiological arousal. *Journal of Architectural and planning research, 7*(1), 13-20.

Moss, S. (2016, May 28). *Inducing moods or emotions.* Retrieved March 29, 2017, from Sicotests: http://www.sicotests.com/psyarticle.asp?id=108

NOS. (2017, February 23). *Bijna kwart van de stemgerechtigden is ouder dan 65*. Retrieved February 23, 2017, from NOS: http://nos.nl/artikel/2159576-bijna-kwart-van-de-stemgerechtigden-is-ouder-dan-65.html

Patton, M. Q. (1990). *Qualitative evaluation and research methods* (Vol. 2). Newbury Park, CA: Sage.

Pears, A. (1998). *STRATEGIC STUDY OF HOUSEHOLD.* Brighton: Sustainable Solutions Pty Ltd.

Picard, R. W. (2015). *Presentation: A journey through measurements of the arousal dimension.* MIT Media Lab.

Picard, R. W., Vyzas, E., & Healey, J. (2001). Toward machine emotional intelligence, analysis of affective physiological signals. *IEEE Transactions on pattern analysis and machine intelligence. 23*, pp. 1175-1191. IEEE.

Rooksby, J., Rouncefield, M., & Sommerville, I. (2009, Sep 03). Testing in the Wild: The Social and Organisational Dimensions of Real World Practice. *Computer Supported Cooperative Work (CSCW), 18*(5), p. 559.

Rottenberg, J., Ray, R. D., & Gross, J. J. (2007). Emotion elicitation using films. In J. A. Coan, & J. J. Allen, *The handbook of emotion elicitation and assessment* (pp. 9-28). London: Oxford University Press.

Russel, J. A. (1980, December). A circumplex model of affect. *Journal of Personality and Social Psychology, 39*(6), 1161-1178.

Russel, J. A., & Pratt, G. (1980, February). A Description of the Affective Quality Attributed to Environments. *Journal of Personality and Social Psychology, 38*(2), 311-322.

Scherer, K. R. (2000). Psychological Models of Emotions. In J. C. Borod, *The Neuropsychology of Emotion* (pp. 137 - 162). Oxford: Oxford University Press.

Schlyter, P. (2017, March 5). *Radiometry and photometry in astronomy.* Retrieved April 2, 2017, from Stjarnhimlen: http://stjarnhimlen.se/comp/radfaq.html#10

Sewell, M. (1998). *Use of Qualitative Interviews in Evaluation.* University of Arizona, Tucson and Children, Youth and Families Education Research Network (CYFERnet). Tucson: Point K Learning Center. Retrieved from University of Arizona: https://cals.arizona.edu/sfcs/cyfernet/cyfar/Intervu5.htm

Sifneos, P. (1973). The prevalence of 'alexithymic' characteristics in psychosomatic patients. *Psychother. Psychosom., 22*, 255-262.

Sleeswijk Visser, F., Stappers, P. J., van der Lugt, R., & Sanders, E. B.-N. (2005). Contextmapping: experiences from practice. *CoDesign, 1*(2), 119-149.

Sleeswijk Visser, F., Stappers, P. J., Van der Lugt, R., & Sanders, E. B.-N. (2005). Contextmapping: experiences from practice. *CoDesign, 1*(2), 119-149.

Stappers, P. J., & Sanders, E. (2003). Generative tools for context mapping: tuning the tools. In Loughborough, Taylor, & Francis, *Third International Conference on Design & Emotion* (pp. 85-95). London: CRC Press.

Stern, J. (2012, October 29). *Philips Hue: The Light Bulb You Can Control With Your Phone.* Retrieved February 8, 2017, from ABC News: http://abcnews.go.com/blogs/technology/2012/10/philips-hue-the-light-bulb-you-can-control-with-your-phone/

Taylor, G., Bagby, M. R., & Parker, J. D. (1999). *Disorders of Affect Regulation: Alexithymia in Medical and Psychiatric Illness.* Cambridge: Cambridge University Press.

Taylor, G., Ryan, D., & Bagby, R. (1985). Toward the development of a new self-report alexithymia scale. *Psychother Psychosom., 44*(4), 191-199.

Taylor, S., Jaques, N., Chen, W., Fedor, S., Sano, A., & Picard, R. (2015). Automatic Identification of Artifacts in Electrodermal Activity Data. *Engineering in Medicine and Biology Society (EMBC)* (pp. 1934 - 1937). Milan: IEEE.

Taylor, S., Jaques, N., Chen, W., Fedor, S., Sano, A., & Picard, R. (2015, August). *EDA Explorer.* Retrieved June 22, 2017, from EDA Explorer: http://eda-explorer.media.mit.edu

Taylor, S., Jaques, N., Chen, W., Fedor, S., Sano, A., & Picard, R. (2017). *FAQs.* Retrieved July 15, 2017, from EDA Explorer: http://eda-explorer.media.mit.edu/info/

Thapan, K., Arendt, J., & Skene, D. J. (2001, August). An action spectrum for melatonin suppression: evidence for a novel non-rod, non-cone photoreceptor system in humans. *Journal of Physiology, 535*(1), 261-267.

Valdez, P., & Mehrabian, A. (1994, December). Effects of color on emotions. *Journal of experimental psychology, 123*(4), 394-409.

Van Uilenburg, H., Den Uyl, M., Israel, M., & Ivan, P. (2008). Advances in face and gesture analysis. *Proceedings of MB , 13*, 371-372.

Vastenburg, M., Romero, N., & Desmet, P. (2016). *Pick-A-Mood manual: Pictorial self-report scale for measuring mood states.* Delft: Delft University of Technology.

Villon, O., & Lisetti, C. (2006). Toward Building Adaptive User's Psycho-Physiological Maps of Emotions using Bio-Sensors. *1rst Workshop on Emotion and Computing at KI 2006, 29th Annual Conference on Artificial Intelligence* (pp. 35-38). Bremen: Eurecom.

Vogels, I. (2008). Atmosphere Metrics. In J. H. Westerink, M. Ouwerkerk, T. J. Overbeek, W. Pasveer, & B. de Ruyter, *Probing Experience: From Assessment of User Emotions and Behaviour to Development of Products* (pp. 25-41). The Netherlands: Springer.

Vogels, I. M., de Vries, M., & van Erp, T. A. (2008). Effect of coloured light on atmosphere perception. *AIC Interim Meeting, Swedish Colour Centre Foundation* (pp. 15-18). Stockholm: AIC.

Willems, P. (2017). *Mood Recognition and Emphatic Lighting.* University of Twente, Human Media Interaction, Enschede.

Yoto, A., Katsuura, T., Iwanaga, K., & Shimomura, Y. (2007, July 20). Effects of Object Color Stimuli on Human Brain Activities in Perception and Attention Referred to EEG Alpha Band Response. *Journal of Physiological Anthropology, 26*(3), 373-379.

10. Appendix

10.1. Consent form first user test

Informed consent form

Title research:
Responsible researcher:

To be completed by the participant

I declare in a manner obvious to me, to be informed about the nature, method, target and [if present] the risks and load of the investigation.

I know that the data and results of the study will only be published anonymously and confidentially to third parties. My questions have been answered satisfactorily.

[If applicable] I understand that film, photo, and video content or operation thereof will be used only for analysis and / or scientific presentations.

I voluntarily agree to take part in this study. While I reserve the right to terminate my participation in this study without giving a reason at any time.

Name participant: ....

Date: .... Signature participant: ....

To be completed by the executive researcher

I have given an spoken and written explanation of the study. I will answer remaining questions about the investigation into power. The participant will not suffer any adverse consequences in case of any early termination of participation in this study.

Name researcher: ....

Date: .... Signature researcher: ....

10.2. Questionnaire after the first user test

Title research: Emphatic Lighting Questionnaire
Responsible researcher: Pim Willems

Please rate the applicability of each of the following term with respect to the environment you are in, on a 7-poiint scale from “not applicable at all” (1) to “totally applicable” (7). You can just add an “x” in the cell of the chosen rating.

	Not applicable at all						Totally applicable
Cosy	1	2	3	4	5	6	7
Safe	1	2	3	4	5	6	7
Intimate	1	2	3	4	5	6	7
Lively	1	2	3	4	5	6	7
Inspiring	1	2	3	4	5	6	7
Stimulating	1	2	3	4	5	6	7
Terrifying	1	2	3	4	5	6	7
Threatening	1	2	3	4	5	6	7
Tense	1	2	3	4	5	6	7
Formal	1	2	3	4	5	6	7
Chilly	1	2	3	4	5	6	7
Business	1	2	3	4	5	6	7

--

[Optional] Leave your contact information if you want to be informed of the test results:

Name: ___________________________________

E-mail: ___________________________________

10.3. Context mapping diary results

Day 1

The first day of using the context mapping to set the baseline was the most boring of the five days according to the participant. The event that stands out the most is the first event, which is based upon the struggles of the participant with the Empatica E4 wristband. The average assessment of the day concluded that it was a boring day in which she did not do a lot. This had two reasons: First, she did not have her weekly bridge game (because of the summer, and second it was hot on this day (30+ degrees), withholding her from doing active things (like going to the supermarket or visiting someone).

Event 1 Struggling to put the wristband on – 8:40. In the first morning, the participant had to put on the wristband on, which did not go as planned for her. Her mood turned tenser when she struggled on with the wristband, because she did not want to disappoint the research by calling in a problem on the first morning. This mood lasted for some time (at least an hour), but after that she relaxed.

Event 2 Phone call of a nephew – 14:30. In the afternoon the participant received a call by a nephew of her late husband. This nephew talked about his life and how bad his life was going. He talked for around an hour. After the conversation she felt uncomfortable, because she did not know what to do with this call. She described the feeling as a negative feeling, which made her feel confounded because she had no clue what to do this with this phone call.

Day 2

The second day consisted out of two main events, a game of bridge with three friends and a visit by both her grandchildren. The event that had the biggest emotional impact on her was the phone call of her granddaughter about a test result. The average assessment of the day concluded that it was a very positive day in which she did a lot of different things which all turned out positive.

Event 1. Phone call of her granddaughter – 12:45. Her granddaughter called at the lunch and told her about the mark she got for her last test. They had talked about this specific test before and the participant was hoping that her granddaughter got a good mark, because then she would complete the year. When she received the call, and heard about the mark (which was good) she was happy for her granddaughter. This was something which kept her in a positive mood for at least the next hours.

Event 2. Difficult bridge game won – 14:40. During the game of bridge (which lasted from 14:00 – 17:00) she had two difficult bets (including a bluff) which in the end both payed off. She was really excited about outcome of these bets and was actively celebrating this with her partner.
Event 3. Watching a television show – 21:00. In the evening, she was watching a non-fictional tense television series about an abducted child by one of the parents. She was really tense because it was a sad story and she wanted to know if they reporters could bring the child the child back to her mother.
Event 4. Visit of both her grandchildren – 21:45. After the television show ended she got a visit by both her grandchildren. This visit was planned, but that did not make it less positive. She really likes getting visits from her grandchildren.

Day 3

The third day has two parts of data, because she went to the swimming pool for the weekly aqua gym session. This session went well and influenced her mood for the remaining day. The average assessment concluded that because of the aqua swim sessions the rest of the day was pleasant. The day was described as a regular day with not a lot of obligations, but she did have time to go to supermarket and start a new book.

Event 1. Aqua gym in the swimming pool – 9:25 ~ 11:00. The aqua gym session in the morning (between 10 and 11) went good. The main reason this had such a positive influence on her mood was the fact that she could actively follow all instructions. Afterwards she stayed a little while to talk with the other people that attended the aqua gym session.
Event 2. Neighbour's car damage – 17:00. Her neighbour was visiting her in the afternoon when he got a call. His daughter had borrowed his car and got in a little accident, damaging the car while it was parked. She would arrive at their apartment complex to show the damage, so she and her neighbour were both curious about how bad it was and were interested in what had happened. When the daughter arrived, the participant watched from her balcony and saw that the damage wasn't too bad. This event made her in interested, but did not really result in a clear positive or negative mood.
Event 3. Live concert disappointed 20:30. She was looking forward to a live concert (André Rieu) on the television, but the concert did not go as she expected. They played songs she did not like as much as other songs and therefore she became a little disappointed. She did say that

this could happen and that it not affected her a lot, though she became a little down (towards sad) because of it.

Day 4

Day four was the birthday of her only grandson, who she invited to lunch with her at a restaurant (together with his sister). This was a very positive experience on a day at which not a lot happened, also because her regular visit to her daughter in law did not happen (she was on holiday). The day was assessed as a positive day, also because the temperature was really good, not too warm and not too cold.

Event 1. Lunch with the grandchildren – 12:00. For the birthday of her grandson she treated her grandchildren on lunch in a restaurant. She really enjoyed the company of her grandchildren, because this was the first time she went out with both of them. She felt really happy during this event.

Event 2. Compliment by the general practitioner – 13:30. After getting dropped off at home, she walked into the general practitioner (GP). The GP complimented her on how healthy she looked. This compliment was highly appreciated by her, because she sometimes doubts this. This made her proud and happy. Especially because this chained two really good moments together (and was combined with the good weather) she had a really good day.

Day 5

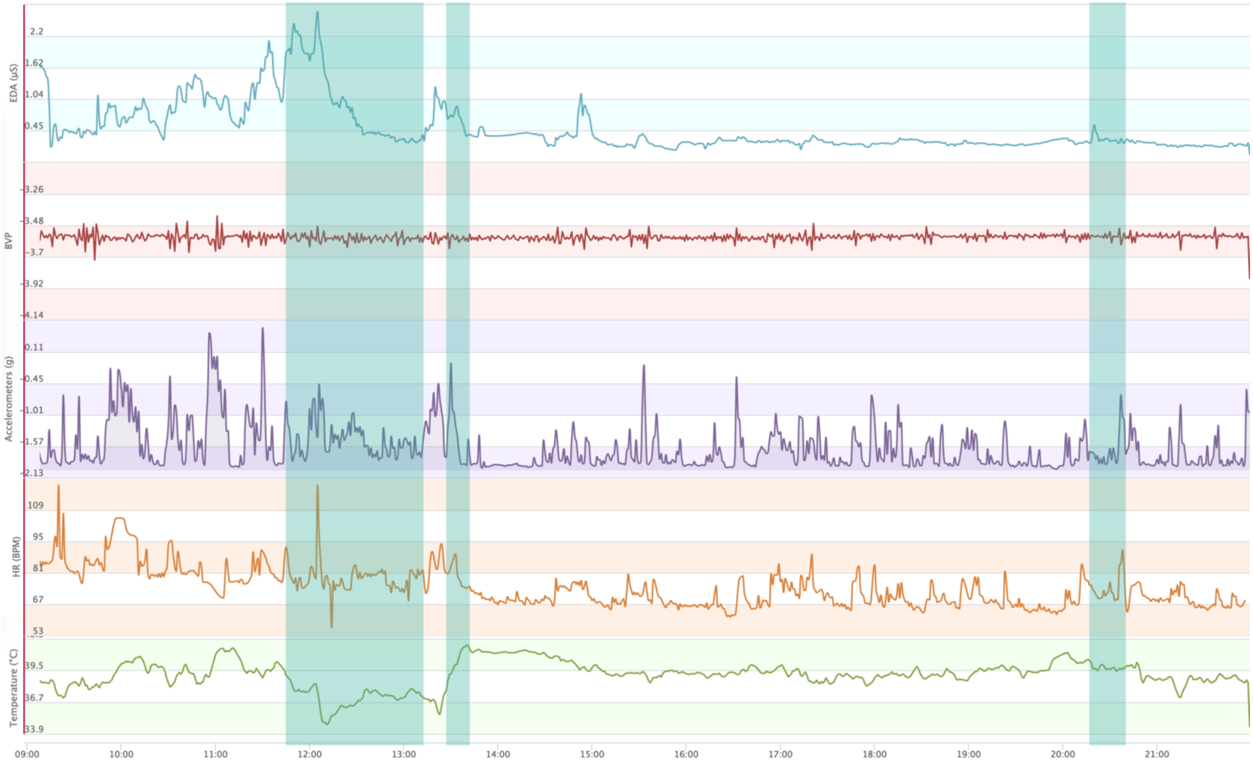
The last day of the week was again a regular day so to say. On average, she felt neutral during the day, with two positive experiences which had about the same positive emotional influence on her. She did some groceries and went to the village centre to get take-out food in the evening.

Event 1. Talked to a friend while doing groceries - 12:15. While walking on the weekly market she ran into a friend who just had a medical procedure. The medical procedure went good, which made the participant happy for the other person. She noticed that this influenced her positively at least for the duration she was shopping.

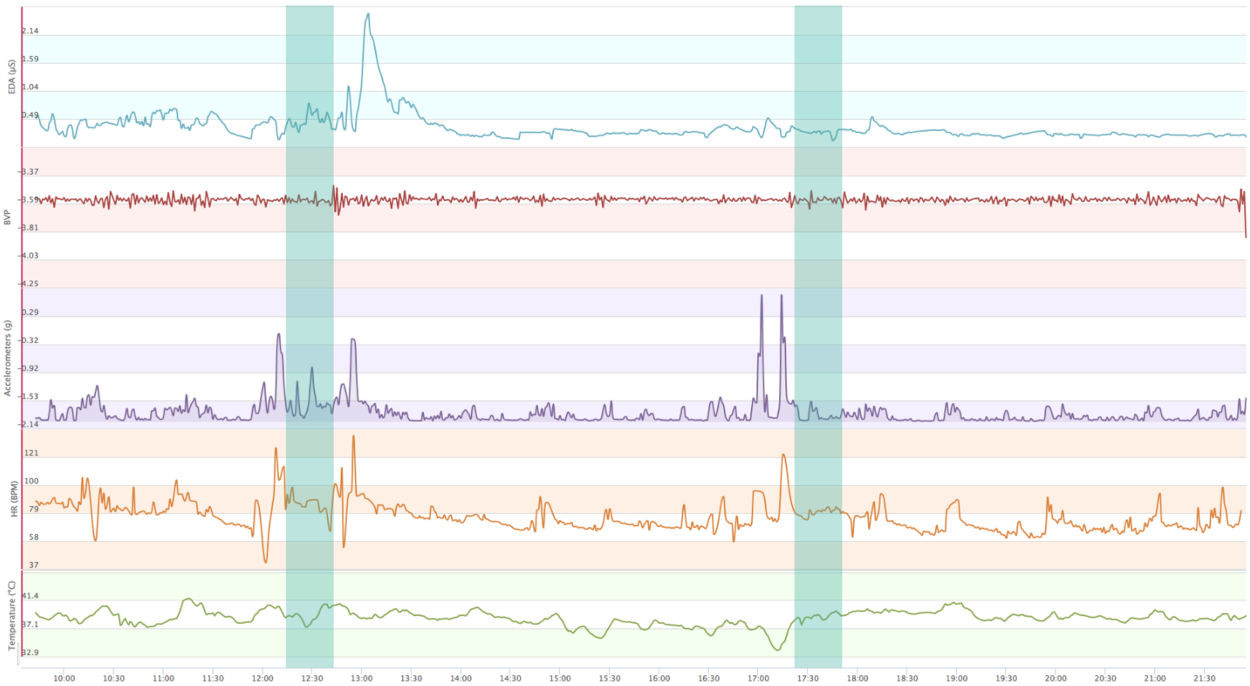
Event 2. Take-out dinner with grandson - 17:15. In the afternoon, she went to get take-out dinner for her and her grandson to eat at her home. Normally she cooks on Fridays for her son (and family), but she really fancied Chinese take-out on this last day of the user test. She liked eating together with her grandson and got in a more positive mood because of it.

10.4. Physiological data with context mapping results for day 4 and 5

Day 4 (Thursday) with the three events marked.



Day 5 (Friday) with the two events marked.



10.5. Interview questions + answers (in Dutch)

Vragen voorafgaand aan het onderzoek

1. Hoe oud ben je? Wat is je geslacht?
   82 jaar, vrouw.
2. Wat is je nationaliteit?
   Nederlandse
3. Hoe ziet je week eruit?
   Ze heeft een wekelijkse routine in welke ze probeert te zorgen dat ze elke dag iemand spreek of in ieder geval ziet. Dit komt erop neer dat ze op maandag bridge speelt in de avond in een grotere groep. Op dinsdag speelt ze bridge met 3 vriendinnen bij 1 van hun thuis. Woensdags doet ze aan aqua gym in het zwembad. Op donderdag gaat ze op bezoek bij haar schoondochter. Op vrijdag komen haar zoon en schoondochter bij haar eten (soms samen met hun kinderen, dus de kleinkinderen). Op zaterdag komen haar beide zoons in de ochtend bij haar vis eten (kibbeling). En op zondag spreekt ze standaard af met 1 vriendin.
   a. Wat zijn de leukste momenten in de week?
      Wisselend, maar het weekend is altijd wel het gezelligst.
   b. Wat zijn de mindere momenten in de week?
      In deze tijd (de zomer) is dit vooral het geval wanneer het zo heet is. Dan kan ze minder doen en zit ze dus meer thuis een beetje niks te doen.
4. Hoe begin je de dag?
   Ik sta uit mezelf op rond acht uur. Dan ontbijt ik met de krant erbij. Dan drink ik een kopje koffie voor ik echt aan de dag begin.
   a. Is je humeur soms aan het begin van de dag slecht zonder goede reden?
      Ja, maar meestal is dit wel met een bepaalde reden. Bijvoorbeeld wanneer ze slechter heeft geslapen of wanneer ze ergens last van heb (bijvoorbeeld de rug).
   b. Bepaald de ochtend hoe de rest van je dag wordt qua humeur?
      Soms wel, maar meestal doet ze wel meerdere dingen op een dag waardoor het humeur veranderd gedurende de dag.
5. Heb je soms (met regelmaat of terugkerende) negatieve gevoelens? Denk hierbij aan eenzaamheid of verdriet?
   Soms wel. Dit heeft alleen niet altijd een duidelijke bron. Soms zit je gewoon een beetje negatief te denken wanneer je alleen in je huis zit. Maar dit is niet heel regelmatig of echt terugkerend.
6. Beschouw je jezelf als een positief of negatief persoon? En waarom?
   Positief. Ze is vrij gelukkig en blij dat ze nog zoveel mag en kan doen op deze leeftijd. Ze heeft nog controle over haar leven, waardoor ze kan doen en laten wat ze wilt.

Dag 1

Evenement 1

1. Wat gebeurde er in je eigen woorden?
   Ze moest voor het eerst de E4 om doen, wat niet meteen goed ging. Het bleek lastig om de band om te krijgen zonder dat hij te los zat. Hier heeft ze 15 minuten mee zitten proberen tot dat het lukte.
2. Waarom vond je dit evenement noemenswaardig?
   Het zorgde voor veel frustraties, waardoor ze een soort negatiever begin van de dag had dan dat ze normaal gewend is.

3. Had dit een grote impact op jou en waarom?
Het had best een grote impact. "Ik had het idee dat vandaag het onderzoek ging beginnen en wou niet meteen aan het begin ook hulp nodig hebben om zoiets als de band om doen". Ze zat hier best even mee omdat ze deels teleurgesteld was in zichzelf en gefrustreerd raakte daardoor.
4. Zorgde dit evenement voor een positieve of negatieve impact op je humeur?
Negatieve impact. Ze werd gefrustreerd en was teleurgesteld. Deze impact bleef ook aanwezig gedurende het begin van de ochtend, maar verdween wel langzaam.

Evenement 2

1. Wat gebeurde er in je eigen woorden?
Ze kreeg een telefoontje van een neef van haar overleden man. Deze neef had ze in twee jaar niet gesproken en begon een verhaal te vertellen over hoe slecht zijn leven was en waar hij allemaal last van had. Hij heeft zeker een kwartier op deze manier verteld en vroeg daarna heel kort hoe het met haar ging ("En hoe is het met jou?") en hing daarna op.
2. Waarom vond je dit evenement noemenswaardig?
Het was een vrij heftig verhaal die ze te horen kreeg, waardoor ze een beetje verward raakte omdat ze niet wist wat ze er mee moest doen.
3. Had dit een grote impact op jou en waarom?
Dit was vooral heel verwarrend. Hij vertelde een best heftig verhaal over allerlei problemen en kwalen in zijn leven, maar dit kwam echt vanuit het niets. Ze spreekt hem te weinig om echt er lang bij stil te staan, maar was daardoor juist meer verbaasd en verward dat hij haar belde.
4. Zorgde dit evenement voor een positieve of negatieve impact op je humeur?
Een korte negatieve impact. Het was sowieso een negatieve gebeurtenis, maar dat heeft verder geen hele lange of diepe impact op haar humeur gehad.

Dag 2

Evenement 1

1. Wat gebeurde er in je eigen woorden?
Ze kreeg een telefoontje van haar kleindochter over een toets resultaat. Ze had een 8 gehaald voor de laatste toets, waardoor ze nu klaar was voor dit studie jaar.
2. Waarom vond je dit evenement noemenswaardig?
Ze had samen met haar kleindochter het hier al vaker over gehad. De kleindochter had in twijfel gezeten, waardoor ze het beiden heel spannend vonden wat het echte resultaat was. Als ze het niet had gehaald moest ze namelijk later (in de vakantie) terug komen voor een herkansing.
3. Had dit een grote impact op jou en waarom?
Redelijk. Ze was in spanning voor het cijfer, want ze gunde haar kleindochter een langere vakantie en niet meer zorgen over dit vak. Hierdoor was ze wel erg enthousiast toen ze het nieuw kreeg, want ze leefde mee met haar kleindochter.
4. Zorgde dit evenement voor een positieve of negatieve impact op je humeur?
Positieve impact. Ze was erg blij voor haar kleindochter. Hierdoor werd de rest van de dag ook een stuk positiever. Met dit nieuws zorgde haar kleindochter voor een humeur impact die ze waarschijnlijk zelf niet eens door had.

Evenement 2

1. Wat gebeurde er in je eigen woorden?
   Tijdens een spelletje Bridge kwamen er twee situaties voor waarin ze ging bluffen om te proberen veel punten binnen te slepen. Beide situaties won ze samen met haar partner wat natuurlijk in veel enthousiasme en trots resulteerde.
2. Waarom vond je dit evenement noemenswaardig?
   Ze deelde het gevoel met haar partner. Het begon als een heel spannende ronde, waarbij ze echt heel onzeker was of ze het wel zou winnen. Als je het dan wint wordt je heel enthousiast, vooral omdat je dat gevoel deelt met een tweede persoon.
3. Had dit een grote impact op jou en waarom?
   Dit zorgde in ieder geval ervoor dat het bridgen van die dag erg leuk was. Door zo'n spannende ronde te winnen weet ze weer waarom ze bridge zo leuk vindt.
4. Zorgde dit evenement voor een positieve of negatieve impact op je humeur?
   Postieve impact. Het zorgde voor een grote postieve impact, aangezien het ervoor zorgde dat ze trots was en tegelijkertijd dit met mensen kon delen (sociaal).

Evenement 3

1. Wat gebeurde er in je eigen woorden?
   Ze keek een televisieprogramma (Ontvoerd) waarin een kind werd ontvoerd naar het buitenland door de vader. De presentator ging samen met de moeder op zoek naar het kind om haar terug naar Nederland te halen. Dit was een erg spannende aflevering of het wel allemaal zou lukken.
2. Waarom vond je dit evenement noemenswaardig?
   Ze merkte dat ze het erg spannend vond en letterlijk op het puntje van haar stoel zat tijdens de conclusie van het programma.
3. Had dit een grote impact op jou en waarom?
   Niet een hele grote impact, maar het zorgde wel voor spanning. Ze was tijdens het programma volledig gefocust op het verhaal en zat er echt in.
4. Zorgde dit evenement voor een positieve of negatieve impact op je humeur?
   Neutraal. Het begin was negatief, aangezien er onrecht was in de wereld waar ze altijd een beetje down van wordt. Maar nadat het goed afgelopen was dit omgeslagen naar een positief gevoel. Over het algemeen was het dus een neutraal gevoel.

Evenement 4

1. Wat gebeurde er in je eigen woorden?
   De beide kleinkinderen kwamen op bezoek in de avond nadat de kleindochter terug kwam van stage.
2. Waarom vond je dit evenement noemenswaardig?
   De kleinkinderen komen niet heel vaak samen op bezoek, maar als ze langs komen is dat erg gezellig en is ze blij dat ze nog de tijd nemen om bij haar langs te komen.
3. Had dit een grote impact op jou en waarom?
   Grote impact, aangezien ze echt blij was om de kleinkinderen te zien. Daarbij was het ook erg gezellig.
4. Zorgde dit evenement voor een positieve of negatieve impact op je humeur?
   Erg positieve impact. Ze was de hele avond enthousiast.

Dag 3

Evenement 1

1. Wat gebeurde er in je eigen woorden?
   Ze gaat elke woensdag ochtend aqua gymmen, waarbij deze ochtend dat ook gebeurde. Het gymmen in het water was deze ochtend erg fijn, waardoor ze echt heel blij werd.
2. Waarom vond je dit evenement noemenswaardig?
   Het evenement zorgde ervoor dat de hele dag eigenlijk positief was. Het was gezond, leuk en gezellig. Dit begin van de dag heeft dus grote impact op haar humeur.
3. Had dit een grote impact op jou en waarom?
   Grote impact. Een combinatie van iets sociaals, sportief en leuks helpt heel erg om je goed te voelen op een dag. Ze krijgt dan een soort trots dat ze dit soort dingen nog kan en wil doen.
4. Zorgde dit evenement voor een positieve of negatieve impact op je humeur?
   Erg positieve impact.

Evenement 2

1. Wat gebeurde er in je eigen woorden?
   Ze was met haar buurman wat aan het drinken toen hij vertelde dat zijn dochter iets met zijn auto had gedaan waardoor ze hem iets moest laten zien. We waren hierdoor beiden benieuwd wat er gebeurd was. Het bleek dat ze de auto beschadigd had omdat er kinderen om de auto heen aan het spelen waren. Dit viel uiteindelijk wel mee, maar ze had toch vanaf het balkon gekeken hoe de buurman de autoschade bekeek en keurde.
2. Waarom vond je dit evenement noemenswaardig?
   Ze was in afwachting van de autoschade en was vooral heel nieuwsgierig wat er nou precies gebeurd was en hoe groot de schade was. Ze vond dit spannend, maar wel op een positieve manier.
3. Had dit een grote impact op jou en waarom?
   Nee, het had een kleine impact. Er gebeurde iets, maar dit had niet echt impact op de verdere dag (behalve het goede verhaal).
4. Zorgde dit evenement voor een positieve of negatieve impact op je humeur?
   Positief. Het zorgde voor spanning op de dag, wat beter is dan wanneer er niks gebeurd op een dag. Het was ook geen erge schade, waardoor het niet echt negatief was.

Evenement 3

1. Wat gebeurde er in je eigen woorden?
   Ze was enthousiast over een live concert van André Rieu welke deze avond werd uitgezonden op televisie. Toen het concert begon bleek het dat ze wat mindere nummers speelden, waardoor het hele concert eigenlijk tegen viel.
2. Waarom vond je dit evenement noemenswaardig?
   Ze was enthousiast van te voren, maar dit veranderde vrij snel in teleurstelling.
3. Had dit een grote impact op jou en waarom?
   Het had niet een hele grote impact op haar, maar het zorgde wel voor teleurstelling. Ze moest namelijk iets anders gaan doen, terwijl ze hier wel naar uit had gekeken.
4. Zorgde dit evenement voor een positieve of negatieve impact op je humeur?
   Negatieve impact. Teleurstelling noemde ze in dit geval negatief. Maar deze negatieve

impact was niet heel groot, want ze had snel iets anders gevonden wat ze is gaan doen.

Dag 4

Evenement 1

1. Wat gebeurde er in je eigen woorden?
   Ze is gaan lunchen met beide kleinkinderen voor de verjaardag van haar kleinzoon. Dit deed ze bij een redelijk nieuws restaurant waar ze altijd al een keer had willen eten. Het bleek ook erg goed te zijn qua eten en gezelligheid.
2. Waarom vond je dit evenement noemenswaardig?
   Het was erg gezellig en ze was nog nooit met haar kleinkinderen alleen ergens heen geweest op deze manier. Dit was iets wat haar nog een tijdje bij zal blijven verwacht ze.
3. Had dit een grote impact op jou en waarom?
   Grote impact. Dit blijft haar waarschijnlijk nog lang bij.
4. Zorgde dit evenement voor een positieve of negatieve impact op je humeur?
   Positieve impact. Na zo'n lunch kan de dag eigenlijk niet meer stuk.

Evenement 2

1. Wat gebeurde er in je eigen woorden?
   Na de lunch met de kleinkinderen werd ik thuis afgezet en kwam ik de huisarts tegen. De huisarts gaf mij een compliment dat ik er zo goed en fit uit zag.
2. Waarom vond je dit evenement noemenswaardig?
   Ze heeft ongeveer een jaar geleden een operatie gehad, dus was erg blij dat juist de huisarts zei dat ze er erg goed uit zag (want hij weet ook van de operatie).
3. Had dit een grote impact op jou en waarom?
   Grote impact. Als iemand die er verstand van heeft zegt dat je er fit of goed uit ziet doet dit wat met je. Dit heeft denkt ze ook met de leeftijd te maken. Het zorgt voor een positieve kijk op de nabije toekomst, want als het nu er goed uit ziet kan ze de komende tijd ook nog de leuke dingen (zoals de lunch) blijven doen.
4. Zorgde dit evenement voor een positieve of negatieve impact op je humeur?
   Het humeur werd alleen maar positiever. Ze had door deze twee evenementen echt een hele goede en vooral positieve dag.

Dag 5

Evenement 1

1. Wat gebeurde er in je eigen woorden?
   Ze was boodschappen aan het doen in de supermarkt en op de markt toen ze een oude bekende tegenkwam. Ze wist dat deze persoon een operatie had gehad, maar ze zag er al weer goed uit. Ze hebben het over haar leven gehad en hoe het ging. Het bleek weer een stuk beter te gaan.
2. Waarom vond je dit evenement noemenswaardig?
   Het was goed om te horen dat het met iemand, waar je om geeft, weer goed gaat. Hierdoor wordt je gewoon blij voor de andere persoon, een soort plaatsvervangend enthousiasme.

3. Had dit een grote impact op jou en waarom?
   Niet heel groot, maar wel zolang ze aan het winkelen was had ze een goed gevoel.
4. Zorgde dit evenement voor een positieve of negatieve impact op je humeur?
   Een positieve impact.

Evenement 2

1. Wat gebeurde er in je eigen woorden?
   Ze heeft samen met haar kleinzoon gegeten omdat haar zoon en schoondochter op vakantie waren. Hiervoor heeft ze chinees opgehaald omdat ze geen zin had om te koken, wat ze normaal gesproken wel doet.
2. Waarom vond je dit evenement noemenswaardig?
   Het was gezellig tijdens het eten en zorgde ervoor dat ze in ieder geval niet alleen hoefde te eten.
3. Had dit een grote impact op jou en waarom?
   Niet heel groot, maar het was wel een beter begin van de avond dan wanneer ze alleen had gegeten. Hierdoor was de avond toch positiever.
4. Zorgde dit evenement voor een positieve of negatieve impact op je humeur?
   Positief, de avond werd hierdoor positiever in zijn totaliteit.

Vragen per dag (zonder lichten)

Dag 1

1. Hoe heb je deze dag ervaren?
   Het was een saaie dag waarop eigenlijk niet heel veel gebeurde, in ieder geval niks wat noemenswaardig was.
2. Hoe zou je je humeur vandaag in het algemeen beschrijven?
   Verveeld. Ze heeft eigenlijk niks gedaan behalve thuis zitten. Dit kwam grotendeels door de warmte buiten.
3. Welk evenement is je het meest bijgebleven en waarom?
   De armband die ze niet om kreeg.

Dag 2

1. Hoe heb je deze dag ervaren?
   Erg goed. Ze heeft veel gedaan op deze dag waarbij de meeste dingen erg leuk waren. Het was dus een hele positieve dag.
2. Hoe zou je je humeur vandaag in het algemeen beschrijven?
   Goed. Door de grote hoeveelheid evenementen (vergeleken met gisteren) was de dag erg positief. Dit komt ook deels omdat de dag ervoor minder leuk was, en daar ga je het toch mee vergelijken.
3. Welk evenement is je het meest bijgebleven en waarom?
   Het telefoontje van de schoondochter over het cijfer welke ze gehaald had voor het vak.

Dag 3

1. Hoe heb je deze dag ervaren?
   Goed. Het was een actieve dag waarbij ze vooral het zwemmen de toon heeft gezet voor de rest van de dag.

2. Hoe zou je je humeur vandaag in het algemeen beschrijven?
   Prettige dag. Er vonden eigenlijk alleen maar positieve dingen plaats op deze dag, waardoor ze in een soort prettig humeur terecht kwam waar ze tevreden mee was.
3. Welk evenement is je het meest bijgebleven en waarom?
   Het zwemmen, dit is het beste begin van de dag die blijheid en actief zijn combineert.

Dag 4

1. Hoe heb je deze dag ervaren?
   Dit was een hele leuke en gezellige dag. Ze is eindelijk bij het restaurant geweest waar ze al een tijdje heen wou en heeft de verjaardag van haar kleinzoon gevierd.
2. Hoe zou je je humeur vandaag in het algemeen beschrijven?
   Erg positief. Het was eigenlijk een aaneenschakeling van twee hele positieve evenementen waardoor het een hele fijne dag was waarop ze een heel positief humeur heeft gekregen.
3. Welk evenement is je het meest bijgebleven en waarom?
   Het lunchen met de kleinkinderen. Dit had ze nog niet eerder gedaan in zo'n setting met de kleinkinderen waar ze erg blij mee was.

Dag 5

1. Hoe heb je deze dag ervaren?
   Dit was een neutrale dag waarbij er niet iets heel geks of iets dergelijks gebeurde. Wel was het weer wat gemoedelijker dan de rest van de week.
2. Hoe zou je je humeur vandaag in het algemeen beschrijven?
   Neutraal of normaal. Het was niet per se negatief, maar was ook niet heel positief.
3. Welk evenement is je het meest bijgebleven en waarom?
   Het gesprek met de vriendin op de markt. Dit was gewoon goed om te horen en dit vind ze fijn om te weten over haar vrienden.

Vragen per dag (met lichten)

Dag 3, 4 en 5

1. Hoe heb je deze avond ervaren?
   Als een normale avond. Er was niet echt een avond waarop er iets gebeurde wat mij emotioneel veranderde. De avonden waren alle drie vrij standaard, wat betekend dat ze of tv aan het kijken was of iets anders voor haar zelf aan het doen was.
2. Hoe zou je je humeur vandaag in het algemeen beschrijven?
   Vrij positief. Er was niet 1 avond waarbij ik in een negatief humeur was. Wel heeft ze soms aangegeven via de app dat het negatief was, maar dit kwam door een combinatie van de lichten en bijvoorbeeld het televisieprogramma.
3. Welk evenement is je het meest bijgebleven en waarom?
   Er is niet echt een evenement in de avond haar bijgebleven. Misschien de eerste keer dat ze merkte dat de lichten veranderden. Ze vond het wel mooi dat dit automatisch ging, maar dat was het dan ook wel.
4. Hoe ging het bedienen van de Android applicatie
   Het bedienen ging heel simpel. Ze kon een icoontje aanklikken en dan werkte het. Wat ze moest invullen was lastiger.

5. Wat vond je van de aantal keren dat de Android applicatie om aandacht vroeg (Pick-A-Mood)?
   Lijkt haar goed. Ze gaf nu soms dezelfde aan, maar vaak verschilde haar antwoord wel over de avond heen.
6. Heb je veel gemerkt van de lichten?
   Ja. Er was veel verschil in hoe licht of donker de lichten stonden. Ze vond de donkere setting wel gezellig, maar dit zorgde er ook voor dat ze minder actief werd wat dan weer een negatieve uitwerking op haar had.
7. Wat voor een effect hadden de lichten op je?
   De lichten zorgden voor een nieuwe sfeer in de woonkamer. Hierdoor veranderde het gevoel dat ze had binnen de woonkamer. Dit zorgde alleen niet voor een echte verandering in humeur aldus de deelnemer. Wel gaf ze aan iets gedeprimeerd te worden van de donkere setting, waardoor het dus wel deels iets aan het humeur veranderde.

Vragen na de eerste twee dagen

1. Hoe heb je de afgelopen dagen ervaren?
   Apart. Ze was in staat om te doen wat ze normaal ook deed, alleen moest bij alles wat ze deed wel rekening houden met de tijd waarop ze het deed en of ze dit moest noteren in het dagboek. Het scheelde wel dat ze later het dagboek mocht invullen en dat het niet ter plaatse hoefde. Maar het was soms wel lastig om even te ontspannen wanneer ze bezig was met iets wat misschien in het dagboek moest komen.
2. Hoe ging het invullen van het dagboek?
   Het dagboeken invullen was vrij gemakkelijk. Vooral omdat ze het later kon toelichten in het interview.
   a. Heb je het als irritant, tijdrovend ervaren?
      Niet echt tijdrovend. Maar zoals ze bij de eerste vraag aan gaf wel als iets wat altijd in je achter hoofd meespeelt en op die manier wel meer tijd op zich neemt dan ze van tevoren had verwacht.
3. Was deze periode een goed voorbeeld van een normale dag uit je leven?
   Ja, dit was een redelijke normale maandag en dinsdag.

Vragen aan het einde van het onderzoek

Na de twee meet dagen en de drie dagen met lichten wordt een interview gehouden waarin de ervaringen van de deelnemer worden besproken. Tijdens dit interview wordt de focus gelegd op het effect van de lichten en de relatie tot het humeur.

1. Hoe heb je de afgelopen week ervaren?
   Het was wel een soort van inbreuk op haar rustige leven. Het was een verandering van het dagelijks leven. Dit was vooral omdat je de hele dag bezig was met de test. Je bent er wel de hele tijd mee bezig. Oh dat moet ik onthouden, en hoe laat is het? Verder was het wel vol te houden. Het zorgde er niet voor dat er iets veranderde in het dagelijks (of wekelijks) ritme.
2. Hoe ging het invullen van het dagboek?
   Viel haar niet tegen. Het was geen negatieve ervaring, maar normaal zou je over dit soort dingen heen leven. Nu houd je de evenementen wat langer vast, omdat je erover moet schrijven. Je wordt er iets bewuster van.

3. Heb je veel gemerkt van de lichten?
   Ik heb niet echt gemerkt dat de lichten veel veranderen. Ze merkte dat de lichten veranderen. Ze had het idee dat er drie soorten lichten instellingen waren die afwisselden.
4. Heb je het idee dat de lichten reageerde op jouw humeur?
   Ze had het idee dat de lampen van kleur veranderden uit zichzelf. Ze had niet het idee dat ze veranderen omdat zij wat gedaan had.
   a. Reageerden ze als je vrolijk was of juist in een negatief humeur?
   Dit is dan ook niet van toepassing.
5. Was deze periode een goed voorbeeld van een normale dag uit je leven?
   Het was een normale week, de lampen hebben me hier ook niet in gehinderd. Dit is over een jaar gezien een normale week. Niks voor het onderzoek hoeven te laten.
6. Wat vond je van het systeem in het algemeen?
   a. De lichten op zichzelf?
      Het was lastig om een gevoel te hebben bij de lichten. Ze had het idee dat ze altijd een gevoel moest hebben bij bepaalde lichten instellingen. De lichten hadden soms een wat lichtere en wat donkerder instelling welke een ander effect op haar hadden. Ze werd iets somberder van de donkere instelling, omdat de wat lichtere setting haar wat actiever maakte waardoor ze ook opgewekte werd.

      De verandering van de lichten was niet altijd even leuk. Dat was moeilijk. Het was niet irritant, want het ging heel geleidelijk. De moeilijkheid kwam vooral van het invullen van de Androidapplicatie.

      Ze had het idee dat ze onrustiger werd van de verandering van de lichten omdat er langzaam iets veranderd. Dat lijkt haar heel gek wanneer de hele kamer van kleur veranderd, dan wil ze weten wat er aan de hand is. Dat vindt ze irritant.

      Wanneer het in mindere mate plaats zal vinden, dus bijvoorbeeld een iets warmere kleur toevoegen aan de bestaande verlichting zou ze het helemaal niet irritant vinden. Dat zou ze zelfs wel gebruiken in huis. Dan zou het wel zo moeten dat ze het bijna niet merkt.
   b. De Android applicatie?
      Erg moeilijk met de Pick-A-Mood. Ze had meer meningen over emoties dan dat er plaatjes waren. Er miste bijvoorbeeld een soort rustige blijheid, maar ook een neutrale emotie optie. Verder had ze graag een beschrijving willen hebben per afbeelding, dat zou haar iets meer zekerheid geven. Aan het einde ging dit wel beter.
7. Heb je het gevoel dat de lichten je humeur positief hebben beïnvloed?

Ja. De sfeer in de kamer zorgt wel voor een ander binnen komen in de kamer. De gezellige setting zorgde ervoor dat ze zich fijner voelde in haar eigen woonkamer vergeleken met de andere setting. Een gezellige lichte setting maakt het opgewekter en positiever voor haar. Dit moet niet te extreem worden. De verlichting moet eigenlijk niet te fel en niet te zacht zijn omdat het anders te depressief (bij donker) of ziekenhuissfeer (bij licht) wordt.